Draft

Columbia River Estuary Recovery Plan Module

Prepared for

NOAA Fisheries

December 1, 2005

Prepared by the

Lower Columbia River Estuary Partnership

Contents

Tables

Figures

Acronyms

cfs	cubic feet per second
CSMEP	Collaborative Systemwide Monitoring and Evaluation Project
DDT	dichlorodiphenyltricholoroethane
EDT	Ecosystem Diagnosis and Treatment
ENSO	El Niño/Southern Oscillation
ENSO	El Niño/Southern Oscillation
ESA	Endangered Species Act
ESU	evolutionarily significant unit
ETM	estuarine turbidity maximum
GIS	geographic information system
HUC	hydrologic unit code
ISAP	Independent Science Advisory Panel
ISRP	Independent Science Review Panel
LCFRB	Lower Columbia Fish Recovery Board
LCRANS	Lower Columbia River Aquatic Nonindigenous Species Survey
LCREP	Lower Columbia River Estuary Partnership
LIDAR	Light Detection and Ranging
MR&E	monitoring, research, and evaluation
NASQAN	National Stream Quality Accounting Network
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPCC	Northwest Power and Conservation Council
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PDO	Pacific Decadel Oscillation
PNAMP	Pacific Northwest Aquatic Monitoring Partnership
RM	river mile
WDF	Washington Department of Fisheries

Glossary

Alevins: Salmonids at the life stage between egg and fry.

Bathymetry: The measure of the depths of oceans, seas, or other large bodies of water.

Detritus: Loose mixture of organic material (dead plants and animals) and inorganic material (rock fragments) that results directly from disintegration of the material.

Dikes: Earthen walls constructed to contain water; sometimes constructed around dredged material disposal sites but more commonly constructed as flood protection.

Dredging: The removal or redistribution of sediments from a watercourse

Ecosystem: A community of organisms in a given area together with their physical environment and its characteristic climate.

El Niño/Southern Oscillation: A shorter term climate effect that alternates between cold and warm phases approximately every 3 to 7 years; is associated with a warm-water current that periodically flows southward along the coast of Ecuador, and the southern oscillation in the atmosphere; affects climatic and ocean conditions throughout the Pacific region.

Emergent marsh: A wet, springy peatland that occurs along the edges of lakes and streams and is covered by grass-like sedges and fed by minerals washing in from surrounding lands.

Estuarine turbidity maximum (ETM): A circulation phenomenon in an estuary that traps particles and promotes biochemical, microbial, and ecological processes that sustain a dominant pathway in the estuary's food web.

Estuary: A semi-enclosed coastal body of water with a free connection to the open ocean in which sea water is diluted with runoff from the land.

Exotic species: A non-native plant or animal deliberately or accidentally introduced into a new habitat.

Fingerling: Juvenile salmonid less than 1 year old.

Fluvial: Involving running water; usually pertains to stream processes.

Forested wetlands: Wetlands that occur in palustrine and estuarine areas and possess an over story of trees, an understory of young trees or shrubs, and a herbaceous layer.

Freshet: High stream flow caused by rains or snowmelt and resulting in the sudden influx of a large volume of freshwater in the estuary.

Fry: Juvenile salmonids that have absorbed their egg sac.

Genetic diversity: Variation at the level of individual genes (polymorphism); provides a mechanism for populations to adapt to their ever-changing environment.

Habitat capacity: A category of habitat assessment metrics, including "habitat attributes that promote juvenile salmon production through conditions that promote foraging, growth, and growth efficiency, and/or decreased mortality" (Fresh et al. 2005).

Habitat connectivity: A measure of how connected or spatially continuous habitats occur in a larger ecosystem.

Habitat opportunity: A category of habitat assessment metrics that evaluate the capability of juvenile salmon to access and benefit from the habitat's capacity. (Fresh et al. 2005).

Habitat: The physical, biological, and chemical characteristics of a specific unit of the environment occupied by a specific plant or animal.

Limiting factor: Physical, chemical, or biological features that impede species and their independent populations from reaching viability status.

Littoral cell: Of, relating to, or situated or growing on or near a shore; especially of the sea.

Macrodetritus: Dead or dying matter from a plant or animal that is visible to the unaided eye; usually larger than 1 to 2 mm in diameter.

Microdetritus: Dead or dying matter from a plant or animal; usually smaller than 1 to 2 mm in diameter.

Navigational channels: Channels in estuaries created, deepened, and maintained by dredging to enable ships to navigate safely into and out of ports, harbors, and marinas without running aground.

Ocean type: Of or relating to salmonid juveniles that enter the estuary as fry or fingerlings and stay in the estuary for weeks or months before entering the ocean; examples are chum and subyearling chinook.

Overbank flooding: Out-of-bank flooding resulting from flow events that exceed the bankfull.

Pacific Decadel Oscillation: A longer term climate effect that alternates between cold and warm phases approximately every 30 years.

Pelagic: Pertaining to the open ocean.

Pinnipeds: Seals, sea lions, and walruses that belong to the taxonomic suborder called Pinnipedia, or the "fin-footed." Pinnipeds are carnivorous aquatic mammals that use flippers for movement on land and in the water.

Plume: The layer of Columbia River water in the near-shore Pacific Ocean.

Polychlorinated biphenyls (PCBs): A group of synthetic, toxic industrial chemical compounds that are chemically inert and not biodegradable; they once were used in making paint and electrical transformers.

Polycyclic aromatic hydrocarbons (PAHs): A group of more than 100 different chemicals that are formed during the incomplete burning of coal, oil and gas, garbage, or other organic substances like tobacco or charbroiled meat.

Population: A distinct breeding unit of a species that exhibits similar life history strategies.

Redds: Spawning nests used by trout and salmon.

Salmonid population viability: Measure of the status of anadromous salmonids that uses four performance criteria: abundance, productivity, spatial distribution, and diversity.

Salmonid: Any member of the family Salmonidae, which includes the salmon, trout, char, whitefishes, and grayling of North America.

Sediment: Material in suspension in water or recently deposited from suspension; in the plural, all kinds of deposits from the waters of streams, lakes, or seas.

Smolts: Juvenile salmonids that have left their natal stream and are headed down river toward the ocean.

Stream type: Of or relating to salmonid juveniles that rear in freshwater for a year or more before entering the ocean.

Threat: A human action or natural event that causes or contributes to limiting factors; threats may be caused by past, present, or future actions or events.

Turbidity: The amount of particulate matter suspended in water.

Viable: Capable of growing or developing.

Executive Summary

What is the Estuary Recovery Module?

This estuary recovery module is one element of a larger planning effort led by the National Marine Fisheries Service (NMFS, also known as NOAA Fisheries) to develop recovery plans for Endangered Species Act-listed salmon and steelhead trout in the Columbia River basin. Recovery plans are being developed for each of the 13 evolutionarily significant units (ESUs) in the Columbia. Figure ES-1 shows the 13 listed ESUs in the Columbia River basin grouped by region. The regions include the Lower Columbia, Upper Willamette, Middle Columbia, Snake, and Upper Columbia River ESUs. Within each of the regions, the ESUs have unique geographical boundaries that are based on similarities among populations.

This estuary recovery module is one of several modules intended to complement recovery plans by identifying actions that can improve the survival of salmon and steelhead in conjunction with efforts to improve tributary habitats. Separate modules address harvest, hatcheries, and hydroelectricity production. Additional effort on this module is anticipated in 2006 to make refinements, to integrate this module with others, and to identify program and implementation considerations.

The goal of this estuary module is to prioritize management actions that, if implemented, would reduce the impacts of the limiting factors that salmon and steelhead encounter during migration and rearing in the estuary and plume ecosystems. To accomplish this, changes in the physical, biological, or chemical conditions in the estuary are reviewed for their potential to affect salmon and steelhead. Then, the underlying causes of limiting factors are identified and prioritized based on the significance of the limiting factor and each cause’s contribution to one or more limiting factors. These causes are referred to as threats and can be either human or environmental in origin. Finally, management actions are identified that are intended to reduce the threats and increase the survival potential of salmon and steelhead during estuarine rearing and migration.

This estuary recovery module is intended to help answer questions about the degree to which the estuary and plume can contribute to salmon and steelhead recovery efforts throughout the Columbia River basin. The state of the science surrounding the estuary and plume is such that quantitative answers to questions about the estuarine ecology are not necessarily available at this time. This is true in part because of the complexity of the ecological processes in the estuary and plume. However, it is also true because the Columbia River estuary and plume are only now being studied at a level of detail that allows knowledge about this portion of the Columbia River ecosystem to be integrated into the understanding of life history patterns that have been well documented in the upstream portions of the basin.

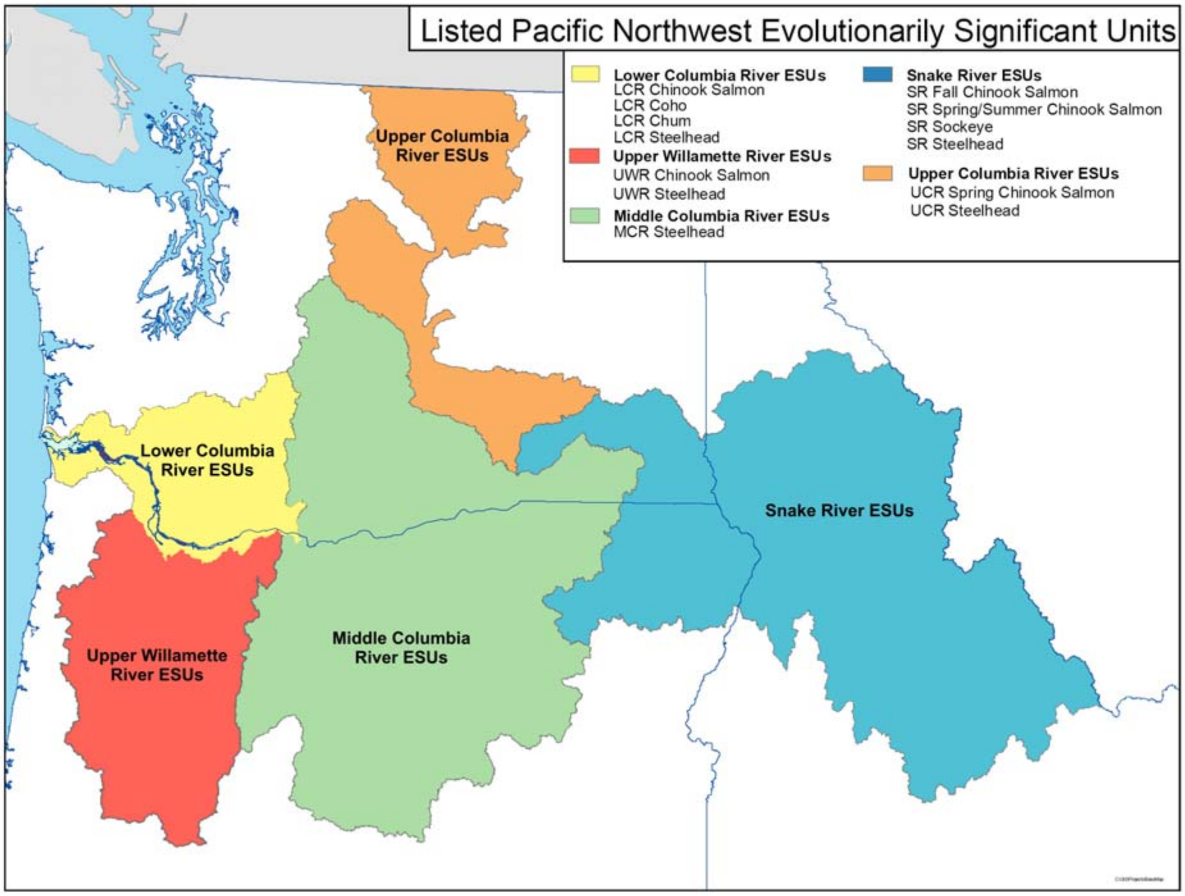

FIGURE ES-1
Listed Pacific Northwest ESUs

This estuary recovery module is a synthesis of diverse literature sources and the direct input of estuary scientists. Several key documents were used extensively as a platform for the estuary recovery module because of the similarities in their purpose and content. One of those documents is the *Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan and Supplement* developed by the Lower Columbia River Estuary Partnership for the Northwest Power and Conservation Council in 2004. NOAA's Northwest Fisheries Science Center recently produced two important technical memoranda for the estuary: *Salmon at River's End* (Bottom et al. 2005) and *Role of the Estuary in the Recovery of Columbia River Basin Salmon and Steelhead* (Fresh et al. 2005). These two memoranda were also used extensively. Other sources were consulted as well, including many primary sources. Area experts from NOAA's Northwest Fisheries Science Center, other NMFS staff, Lower Columbia River Estuary Partnership staff, and the Lower Columbia Fish Recovery Board provided input and advice on scoring and evaluation processes.

Why Are the Estuary and Plume Important?

The Columbia River estuary and plume represent one of three major stages in the life cycle of salmon and steelhead. In tributaries, adults spawn and juveniles rear in freshwater. In the ocean, juveniles grow to adults as they forage in food-rich environments. The estuary is where juveniles and adults undergo vast physiological changes needed to transition to and from saltwater. In addition, a properly functioning estuary provides high growth opportunities and refugia from predators.

But why are the estuary and plume so important? The answer lies in the very reason that salmonids grew in numbers to an estimated 16 million over the past 4,000 years. Salmon and steelhead were successful because they exploited every habitat niche available to them. They did this by employing a variety of strategies that allowed them to use many diverse habitats across a wide geographic space. In fact, the distribution of salmon and steelhead historically spanned thousands of river miles throughout the basin.

If this were not remarkable enough, salmon and steelhead's traits allowed them to use habitats at varying times, and this is why the estuary and plume are so important. Every downstream-migrating juvenile salmon or steelhead must use the habitats of the estuary to complete their life cycle. If the progeny of the 16 million adult salmon and steelhead that historically made use of the estuary had converged on the estuary at one time, there likely would not have been enough habitat and food to sustain them. So they developed strategies to enter the estuary at different times, at different sizes, using unique habitats. In fact, it has been hypothesized that each individual population's use of estuarine habitats is discrete in terms of time and location of use. The implication for the estuary and plume today is that the area's habitats must be available through time and space and at sufficient quantities to support more than 150 distinct salmon and steelhead populations, which represent 13 ESUs that use many different life history strategies.

The number of adult salmon and steelhead that return to the Columbia River basin each year varies, but in recent years returns have been approximately 1.25 million. To achieve these returns, approximately 200 million juveniles are produced in tributary or mainstem gravels of the river or in hatchery ponds. This means that less than 1 percent of the juveniles return to the Columbia River as adults. This also means that 99 percent of these fish die somewhere along the way. Understanding the extent to which the estuary and plume contribute to this loss is essential to the ultimate recovery of salmon and steelhead ESUs throughout the basin.

What Is the Condition of the Estuary Now?

Flows, Dikes and Filling, and Sediment

The estuary and plume are considerably degraded compared to only 200 years ago. In terms of absolute size, the estuary tidal prism is about 20 percent smaller than it was when Lewis and Clark camped along the Columbia's shore (Lower Columbia River Estuary Partnership 2004a). This reduction in estuary size is due mostly to dike and filling practices used to convert the floodplain to agricultural, industrial, commercial, and residential uses. Instream flows entering the estuary also have changed dramatically—there has been a 44 percent decrease in spring freshets or floods, and the annual timing, magnitude, and duration of flows no longer resemble those of the historical hydrograph in the Columbia River (Jay and Kukulka 2002). Changes to the hydrograph are attributed to flow regulation by the hydrosystem, water withdrawal for irrigation and water supplies, and climate fluctuations.

Flow alterations and dike and filling practices are significant to salmon and steelhead in several ways. Historically, vegetated wetlands within the floodplain supplied the estuary with its base-level food source: macrodetritus. The near elimination of overbank events and the separation of the river from its floodplain have altered the food web by reducing macrodetritus inputs by approximately 84 percent (Bottom et al. 2005). At the same time, phytoplankton detrital sources from upstream reservoirs now dominate the base of the food chain. The substitution of food sources likely has profound effects on the estuary ecosystem. In addition, access to and use of floodplain habitats by ocean-type ESUs (salmon and steelhead that typically rear for a shorter time in tributaries and a longer time in the estuary) have been severely compromised through alterations in the availability and presence of these critical habitats.

The timing, magnitude, and duration of flows also have important ramifications to in-channel habitat availability and connectivity. Sand and gravel transport along the river bottom is highly correlated to flow. By reducing the magnitude and duration of flows, erosion and accretion processes no longer function as they have for thousands of years. This may have far-reaching consequences to the estuary, plume, and shore lands north and south of the river’s mouth. At the same time, upstream dams have prevented sand and gravel from entering the estuary, while dredging activities have exported sand and gravel out of the estuary. Studies have shown that sand and gravel are exported from the estuary at a rate three times higher than that at which they enter the estuary. The full impact of these changes is unknown; however, sediment transport is a primary habitat-shaping force that determines the type and location of habitats distributed in the estuary and plume. Recent bathymetry modeling efforts and new research on juvenile salmonid use of estuary habitats will help characterize juvenile mortality in the near future. Decreases in sediments also improve water clarity and increase the effectiveness of predators that consume juvenile and adult salmon and steelhead.

Water Quality

Water quality in the estuary and plume has been degraded by human practices from within the estuary and also from upstream sources. Some important indicators of water quality degradation found in the estuary are increased temperatures and the presence of toxic contaminants. A recent study of contaminant impacts on juvenile salmon estimated delayed disease-induced mortalities of 3 and 18 percent as a result of contaminant stressors for residencies in the Columbia River estuary of 30 to 120 days, respectively (Loge et al. 2005). If this estimate is accurate, threats from contaminants may exceed those from Caspian tern predation.

Elevated temperatures of water entering the estuary are a threat to salmon and steelhead. Summer water temperatures entering the estuary are on average 4 degrees warmer today than they were in 1938 (Lower Columbia Fish Recovery Board 2004). The upper range for cold-water fish, including salmon and steelhead, is about 20° to 24° Celsius. Temperatures exceeding this threshold have been occurring earlier in the year and more frequently since 1938 (as measured at Bonneville Dam). Degradation of tributary riparian habitat caused by forest, residential, commercial, and industrial practices, as well as reservoir heating, is responsible for increased temperatures.

Many contaminants are found in the estuary and plume. Some of them are water-soluble agricultural pesticides and fertilizers such as simazine, atrazine, and diazinon. Industrial contaminants include polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). Concentrations of these substances, and others, are found throughout the estuary, sometimes near cities and other times in bays and shallows where low-velocity flows allow suspended contaminants to settle. Salmon and steelhead are affected by contaminants through short-term exposure to lethal substances or through longer exposures to chemicals that accumulate over time and magnify through the food chain. Ocean-type ESUs are more susceptible to bioaccumulation than stream-type ESUs; however, both are equally vulnerable to acute exposures (stream-type ESUs are those ESUs that typically spend longer periods in tributaries and less time in the estuary).

Food Web and Species Interactions

The Columbia River estuary represents a distinct ecosystem that is a unique expression of biological and physical interactions. As physical and biological changes occur in the estuary, the ecosystem responds to those changes. There is general agreement that the estuary ecosystem is degraded and no longer provides the same level of support to native species assemblages that it did historically. Unfortunately, this field of research is perhaps the least understood, and its impact on salmon and steelhead is not well documented or studied.

Limiting factors related to the food web and species interactions can be thought of as the product of all the threats to salmon and steelhead in the estuary. Some examples are easy to understand, but others are subtle and far-reaching. Caspian terns are a good example of an ecosystem shift that is easy to understand. New islands formed through the disposal of dredged materials attracted terns away from traditional nesting areas. Reduced sediment in the river increased terns' efficiency in capturing steelhead juveniles migrating to saltwater at the same time that the birds need additional food for their broods. The result is a predator/prey shift in the estuary that has increased mortality for steelhead juveniles. Double-breasted cormorants are suspected of preying on juvenile salmonids in similar numbers; however, they have been studied much less than terns have.

Other shifts in the ecosystem are more complex, and it can be difficult to understand whether or how they affect salmon and steelhead. For example, the shift from macrodetritus-based primary plant production to phytoplankton production strikes at the most elemental level of the food chain in the estuary; however, what this means to salmon and steelhead—or, for that matter, to the entire estuary ecosystem—is unknown. The introduction of exotic species is another poorly understood ecosystem alteration. Examples of exotic species thriving in the estuary include 21 new invertebrates, plant species like Eurasian water milfoil, and exotic fish like shad. Shad in particular, because of the sheer tonnage of their biomass, undoubtedly play a large role in the degradation of the estuary ecosystem.

Other Threats

The estuary also is influenced by a number of physical structures that contribute to the estuary's overall degradation, but the extent of their impacts to salmon and steelhead is poorly understood. Structures in the estuary number in the thousands. Over-water and instream structures alter river circulation patterns, sediment deposition, and light penetration, and they form microhabitats that often benefit predators. Examples of structures include jetties, pile dikes, rafts, docks, breakwaters, bulkheads, revetments, groins, and ramps.

Ship wake stranding is an example of another threat to salmon and steelhead in the estuary. A study in 1977 by the Washington Department of Fisheries estimated that more than 150,000 juvenile salmonids, mostly chinook, were stranded on five test sites as a result of ship bow waves striking shorelines (Bauersfeld 1977). Additional studies since the Bauersfeld study have not documented the same level of mortality. New studies by the University of Washington and the Portland District of the U.S. Army Corps of Engineers may shed additional light on this topic in the near future. This threat is most detrimental to ocean-type juvenile fry that are less than 60 millimeters long and rear inches from shore.

What Actions Can Improve Salmon and Steelhead Survival?

This estuary recovery module identifies management actions to improve the survival of salmon and steelhead migrating and rearing in the estuary and plume environments. These actions were evaluated in Chapter 5 based on their potential to improve salmon and steelhead survival, their feasibility, and their relative costs. Table ES-1 shows the results of the evaluation. Survival improvements and costs are explained more thoroughly in Chapter 5.

TABLE ES-1
Prioritization of Management Actions

Action	Survival Improvement	Cost	Priority
Restore off-channel habitat by breaching (or lowering) dikes and levees where possible.	High	Medium	1
Reduce the abundance levels of Caspian terns nesting on islands created by disposal of dredged material.	Medium	Low	1
Protect remaining high-quality off-channel habitat from degradation through regulatory, fee simple, and less-than-fee acquisition.	Medium	Medium	2
Upgrade up-river irrigation structures using water conservation best management practices to reduce evaporation and conveyance losses to improve estuary instream flows.	Medium	Medium	2
Implement stormwater and runoff best management practices in cities and towns.	Medium	Medium	2
Monitor the estuary for contaminants and restore contaminated sites where appropriate.	Medium	Medium	2
Implement pesticide and fertilizer best management practices to reduce estuary and upstream sources of toxic materials entering the estuary.	Medium	Medium	2
Protect intact riparian areas and restore riparian areas that are degraded.	Medium	Medium	2
Remove jetties and navigational structures that have low navigational value but high impact on estuary circulation and/or juvenile predation effects.	Medium	Medium	2
Establish legal instream flows for the Columbia River and tributaries that would prevent further degradation of downstream ecosystems.	Medium	Medium	2

Remove tide gates where appropriate.	Medium	Medium	2
Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.	Medium	Medium	2
Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities in the estuary.	Medium	Medium	2
Implement water conservation best management practices for public and private water purveyors.	Low	Low	2
Study and mitigate the effects of entrapment of sediment in reservoirs.	Low	Low	2
Reduce the square footage of over-water structures in the estuary.	Low	Low	2
Increase macrodetrital inputs and other historical food sources in the estuary to compensate for reservoir phytoplankton production, which is a permanent ecosystem alteration.	Low	Low	2
Manage the hydrosystem to reduce reservoir surface heating.	Low	Low	2
Manage smallmouth bass, walleye, and channel catfish to prevent increases in abundance.	Low	Low	2
Reduce the effects of vessel wake stranding in the estuary.	Low	Low	2
Reduce the impacts on salmonids by pinnipeds.	Low	Low	2
Reduce the abundance levels of shad entering the estuary.	Low	Low	2
Implement best management practices to prevent new introductions of invertebrates in the estuary.	Low	Low	2
Upgrade tide gates where (1) no other option exists, (2) structures can provide appropriate access for juveniles, and (3) ecosystem function would be improved over current conditions.	Low	Low	2
Increase the effectiveness of aquatic noxious weed laws through education, monitoring, and enforcement.	Low	Low	2
Locate sources of industrial and commercial pollutants and take steps to reduce inputs.	Medium	High	3
Protect and restore timberland riparian areas for shade and future wood sources.	Medium	High	3
Incorporate estuary flow considerations into management of the hydrosystem to increase spring freshet flows.	Low	Medium	3
Incorporate estuary flow considerations into management of the hydrosystem to adjust the timing and increase the magnitude and frequency of flows to better mimic historical conditions.	Low	Medium	3
Increase spring flows to enhance the transport of sand and gravels through the estuary, plume, and ocean nearshore.	Low	Medium	3
Incorporate water availability analysis in land use planning activities to ensure efficient use of water.	Low	Medium	3

Achieving a measurable level of survival improvement for salmon and steelhead in the estuary will require significant effort and dedicated resources applied over a sustained period. The estuary and plume are degraded as a result of cumulative changes that have occurred over the past 200 years. Today the human population in the basin is approximately

5 million, with about half of those people living in the lower Columbia region. Population growth estimates indicate that between 40 and 100 million people will live in the basin by the end of the twenty-first century. Given this expected influx of people, increasing the survival of salmon and steelhead in the estuary will require more than slowing the rate of habitat degradation; it will require positive changes in the conditions that salmon and steelhead encounter in the estuary.

This estuary recovery module suggests that of the management actions in Table ES-1 will need to be implemented, to the extent practicable, to improve estuary and plume survival and to meaningfully contribute to the recovery of Columbia River salmon and steelhead. This is because many of the actions have only limited potential for implementation.

CHAPTER 1

The Columbia River Estuary and Plume

Purpose of the Estuary Recovery Plan Module

The purpose of this estuary recovery plan module is to identify and prioritize management actions that, if implemented, would reduce threats to salmon and steelhead in the Columbia River estuary and plume. This was accomplished by reviewing and synthesizing current literature and gaining input and guidance from area experts, including staff at NOAA's Northwest Fisheries Science Center.

The estuary recovery plan module identifies and prioritizes salmon and steelhead limiting factors (see Chapter 3) and links them to the underlying environmental and human threats that have contributed to abundance declines in the estuary (see Chapter 4). Threats are prioritized based on the priority of the limiting factors they contribute to and their relative contribution to those limiting factors. Management actions that have potential to reduce threats are identified in Chapter 5. The management actions are rated for their estimated salmon and steelhead survival improvements and cost. Management actions are then sorted into priorities based on the ratio between survival improvement and cost. Program and implementation considerations will be included in a later draft scheduled for 2006.

The process of identifying and prioritizing management actions has inherent difficulties. Although scientific knowledge about the estuary is advancing, it is still incomplete. In addition, effective management solutions must acknowledge irreversible changes in the estuarine conditions over time, reflect the social and political will of the region, and focus on the biological and physical needs of the fish. In the final analysis, it is likely that science will never fully explain how every action affects the viability of fish. It will be up to current and future residents of the basin to determine how much they are willing to pay or do without in order to return salmon and steelhead to viable levels.

Estuary Characteristics

The historical (circa 1880) total surface area of the Columbia River estuary has been estimated at up to 186 square miles (Thomas 1983, Simenstad et al. 1984 as cited in Lower Columbia River Estuary Partnership 2004a). The current estuary surface area is approximately 159 square miles (Lower Columbia River Estuary Partnership 2004a). The Willamette River is the largest tributary to the lower Columbia River. Other major tributaries originating in the Cascade Mountains include the Sandy River in Oregon and the Washougal, Lewis, Kalama, and Cowlitz rivers in Washington. Coastal range tributaries include the Elochoman and Grays rivers in Washington and the Lewis and Clark, Youngs, and Clatskanie rivers in Oregon. The general geography of the estuary is shown in Figure 1-1.

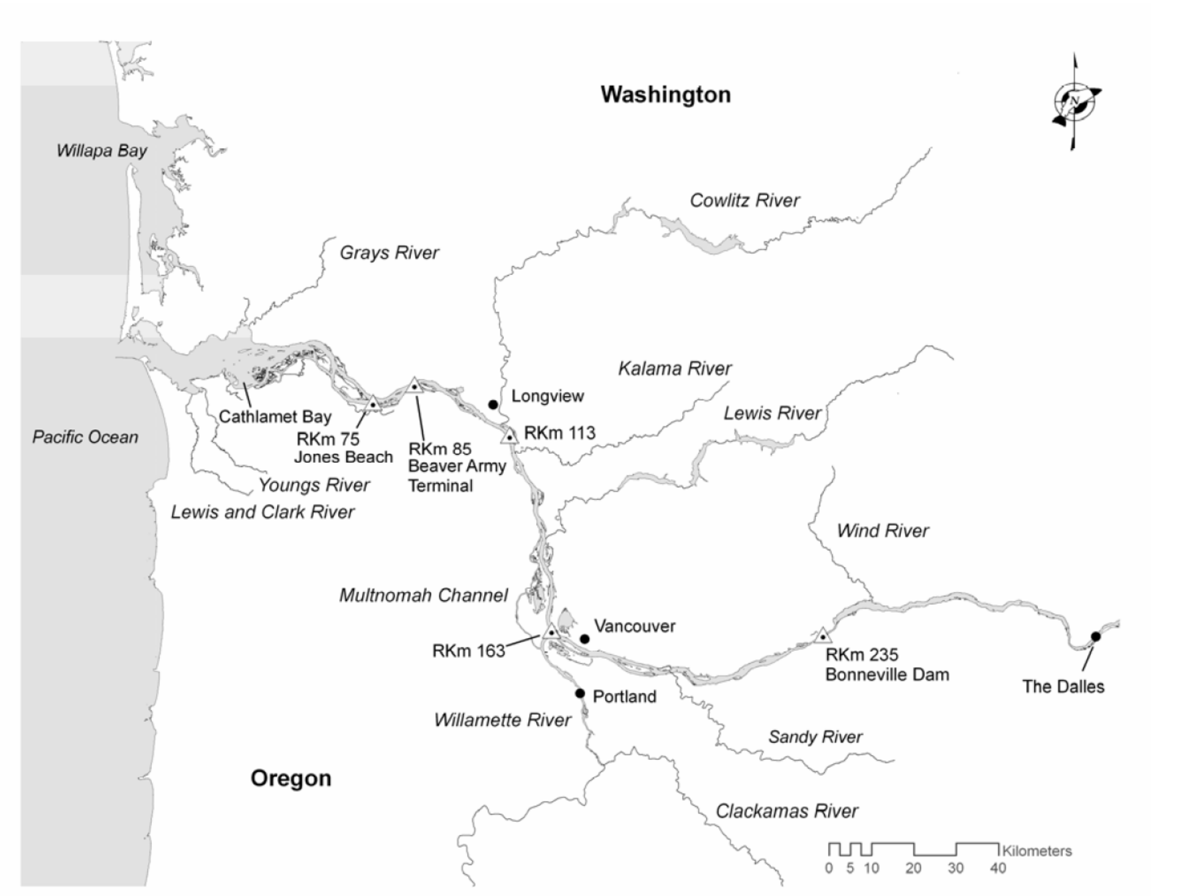

FIGURE 1-1
The Columbia River Estuary and Its Major Tributaries
(Reprinted from Bottom et al. 2005.)

Tidal impacts in water levels are observed as far upstream as Bonneville Dam at River Mile (RM) 146. During low flows, reversal of river flow has been measured as far upstream as Oak Point at RM 53. The intrusion of saltwater is generally limited to Harrington Point at RM 23; however, at lower daily flows saltwater intrusion can extend past Pillar Rock at RM 28.

Today, the lowest river flows occur during September and October, when rainfall and snowmelt are lowest (Lower Columbia River Estuary Partnership 2004a). The highest flows occur from April to June and result from snowmelt runoff. High flows also occur between November and March and are caused by heavy winter precipitation. Discharge at the mouth of the river currently ranges from 100,000 to 500,000 cubic feet per second (cfs). Historically, unregulated flows were both lower and higher—79,000 and 1,000,000 cfs, respectively (Neal 1972 and Lower Columbia River Estuary Partnership 2002 as cited in Lower Columbia River Estuary Partnership 2004a).

Estuary Reaches

For the purposes of this estuary recovery plan module, the estuary is broadly defined to include the entire continuum where tidal forces and river flows interact, regardless of the extent of saltwater intrusion (Fresh et al. 2005, Lower Columbia River Estuary Partnership 2004a). For planning purposes, the upstream boundary is Bonneville Dam and the downstream boundary includes the Columbia River plume. These two divisions—the estuary and plume—have been used extensively in this estuary recovery plan module as distinct zones. Further delineation of the estuary has occurred, including efforts by Thomas (1983), Johnson et al. (2003), and—more recently—the Lower Columbia River Estuary Partnership (2005).

In this estuary recovery plan module, limiting factors, threats, and management actions are identified at the finest reach level possible. In some cases, this may be as general as making a distinction between the estuary and plume. In other cases, additional definition is available at the reach scale. The Lower Columbia River Estuary Partnership, in conjunction with the University of Washington and U.S. Geological Survey, is developing several estuary landscape classifications. Of these overlaying classifications, the estuary recovery module uses the Level 3 Stratum, which organizes the estuary between the mouth and Bonneville Dam into eight lettered reaches (Lower Columbia River Estuary Partnership 2005).

Figure 1-2 shows these eight reaches, which can be described briefly as follows:

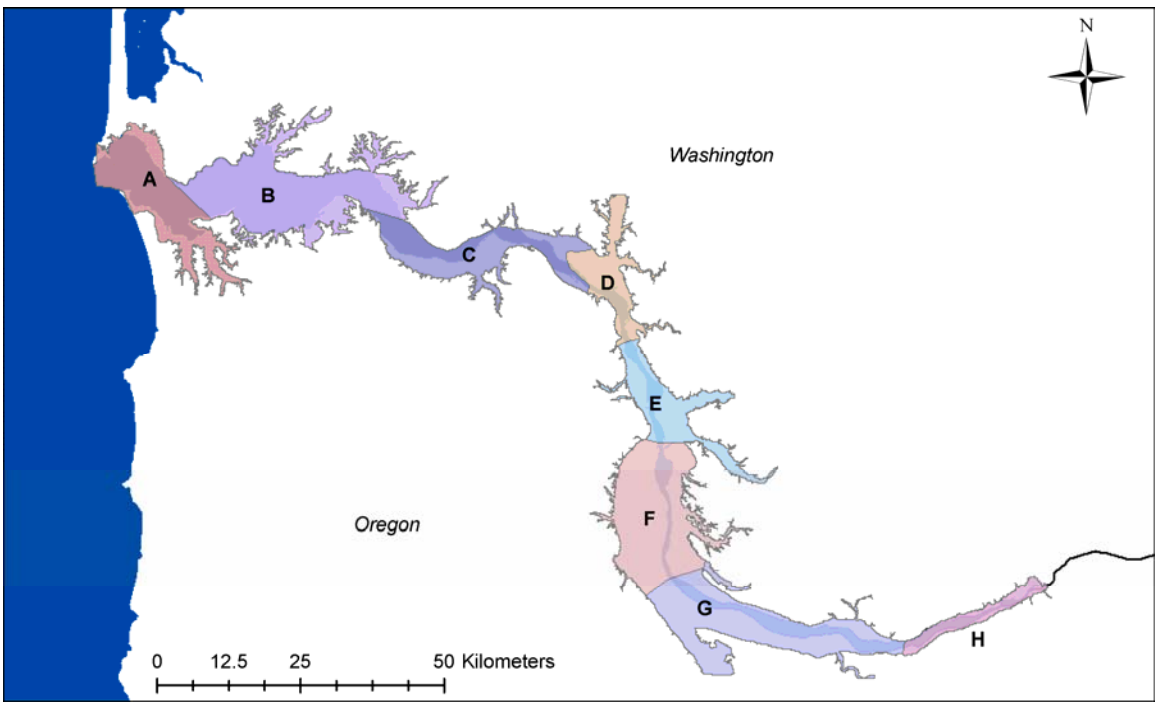

FIGURE 1-2
Lower Columbia River Estuary Reaches
(Reprinted from Lower Columbia River Estuary Partnership 2004a.)

- **Reach A**. This area includes the estuary entrance (Clatsop Spit and Trestle Bay), Bakers Bay, and Youngs Bay. The entrance is dominated by subtidal habitat and has the highest salinity in the estuary. Historically, the estuary entrance was a high-energy area of natural fluvial land forms with a complex of channels, shallow water, and sand bars. Reach A supports the Columbia River plume, which creates a unique low-salinity, high-productivity environment that extends well into the ocean. The dynamic nature of the entrance area has changed as a result of dredging and the construction of jetties. These activities have limited wave action and the marine supply of sediment.

Historically, ocean currents and wave action made Bakers Bay a high-energy area, but both currents and wave action have been altered by dredging and jetty construction. The migration of mid-channel islands toward the interior of Baker Bay also has sheltered the area from wave action. As a result, tidal marsh habitat has recently started to develop in some areas, although much of the historical tidal marsh and tidal swamp habitat has been lost because of dike construction in the floodplain. Given its proximity to the river mouth, Baker Bay consists primarily of brackish water.

Youngs Bay is characterized by a broad floodplain and historically was abundant in tidal marsh and swamp habitat. Diking and flood control structures have been used to convert floodplain habitat in the area to pasture. The remaining fragmented tidal marsh and tidal swamp habitats in Youngs Bay are thought to be different in structure and vegetative community than historical conditions of these habitats.

- **Reach B**. This area includes what has been referred to as the mixing zone (Lower Columbia River Estuary Partnership 2004a), Grays Bay, and Cathlamet Bay. The mixing zone is an area characterized by a network of mid-channel shoals and flats, such as Desdemona and Taylor Sands. It also has the highest variation in salinity within the estuary because of the interactions between tide cycles and river flows. The estuary turbidity maximum (see p. 3-9), which is created through these interactions, is often located within this area of Reach B.

  Grays Bay is found on the Washington side of the river in Reach B. Historically, water circulation in this area was a result of interactions between river flow and tidal intrusion. Pile dikes constructed adjacent to the main Columbia River navigation channel have decreased circulation in Grays Bay. This circulation change is suspected of causing flooding problems in the Grays and Deep River valley bottoms and may have promoted development of tidal marsh habitat in the accreting bay. Dike construction, primarily for pasture conversion, has isolated the main channel from its historical floodplain and eliminated much of the historical tidal swamp habitat.

  Cathlamet Bay is located on the Oregon side of the river in Reach B. This area is characterized by some of the most intact and productive tidal marsh and swamp habitat remaining in the estuary, and a large portion of Cathlamet Bay is protected by the Lewis and Clark National Wildlife Refuge. The western edge of Cathlamet Bay contains part of the brackish oligohaline zone, which is thought to be important during the transition of juvenile anadromous fish from freshwater to saltwater. Portions of Cathlamet Bay have lost substantial acreage of tidal swamp habitat as a result of dike construction. Conversely, tidal marsh habitat has formed along the fringe of dredge disposal locations.

- **Reach C**. This area, which includes deep channels and steep shorelines on both sides of the river, ends just downstream of the city of Longview. The narrow channel structure produces an area dominated more by tidal swamp habitat than by edge habitat (tidal marsh). Reach C is typically dominated by freshwater, except during low river flow or large flood tides. Dike construction and clearing of vegetation have resulted in a substantial loss of tidal marsh habitat on Puget Island and within the Skamokawa and Elochoman floodplains. Wallace Island and Crims Island also are located within Reach C.

- **Reach D**. This area begins just downstream of Longview and ends near the city of Kalama. Reach D is distinct from the downstream reaches in its geology, vegetation, and climate. It includes flows from the Cowlitz and Kalama rivers. Extensive diking and filling around Longview and the mouth of the Kalama River has significantly reduced access to the floodplain. Islands created through the disposal of dredged material are also prevalent. High levels of polychlorinated biphenyls (PCBs) have been detected in the Longview and Kalama industrial area.
- **Reach E**. This area includes the river upstream of the city of Kalama to Woodland. The Lewis River system, including the North Fork and East Fork, flows into the Columbia River in Reach E. Sandy, Goat, Deer, Martin, and Burke islands are included in Reach E. Extensive diking has occurred on Deer Island and around the city of Woodland.
- **Reach F**. This area includes the river upstream of the confluence with the Lewis River up to and including Salmon Creek. Islands included in this reach are Bachelor and Sauvie. Sloughs include the Lake River system and Multnomah Channel. Scappoose Bay is relatively undiked; however, Sauvie Island and Bachelor Island have been extensively diked.
- **Reach G**. This area includes the river upstream of its confluence with Salmon Creek and extends upstream of Reed Island. This reach is dominated by flows from the Willamette, Washougal, and Sandy rivers. The cities of Portland and Vancouver straddle the Columbia River in this reach. Islands included in this reach are Hayden Island, Government Island, Lady Island, and Reed Island. Extensive diking has reduced the floodplain from the confluence of the Willamette River upstream to the mouth of the Sandy River. High readings of PCBs and polycyclic aromatic hydrocarbons (PAHs) are found along the lower Willamette River and the channelized banks of the Columbia River in this reach. Significant numbers of industrial piers and over-water structures line the Willamette and Columbia rivers in this reach.
- **Reach H**. This area includes the river upstream from Reed Island to Bonneville Dam. This reach receives flow from many small tributaries, including Gibbons, Duncan, Hamilton, Hardy, and Multnomah creeks. Notable islands in this reach include Ackerman and Skamania islands. Reach H includes the entrance to the Columbia River Gorge, which is characterized by steep slopes. Little diking has occurred in this area, primarily because of the lack of floodplain.

The Lower Columbia River Estuary Partnership, in conjunction with Pacific Northwest National Laboratory, has further delineated the estuary into discrete management areas at approximately the 6^{th} field hydrologic unit code (HUC). These management areas are geospatially referenced to a variety of data sets that can be used to generate statistics and geographic information system (GIS) maps. Statistics relating to floodplain changes, diking coverage, tide gates, contaminants, structures, and dredge fill locations are included where appropriate. GIS analysis at the reach-scale or the management area-scale (6^{th} field HUC) is currently in progress but will be available in 2006. For additional information, see the

Columbia River Estuary Habitat Monitoring Plan (Lower Columbia River Estuary Partnership 2004b).

Columbia River Plume

The Columbia River plume is generally defined by a reduced-salinity contour near the ocean surface of approximately 31 parts per thousand (Fresh et al. 2005). In high flows, the plume front is easily recognized by the sharp contrast between the sediment-laden river water and the clearer ocean (see Figure 1-3). The plume's location varies seasonally with discharge, prevailing near-shore winds, and ocean currents. In summer, the plume extends far to the south and offshore along the Oregon coast. During the winter, it shifts northward and inshore along the Washington coast. Strong density gradients between ocean and plume waters create stable habitat features where organic matter and organisms are concentrated (Fresh et al. 2005). The Columbia River plume can extend beyond Cape Mendocino, California, and influences salinity in marine waters as far away as San Francisco (Northwest Power and Conservation Council 2000). For the purposes of this estuary recovery plan module, the plume is considered to be off the immediate coasts of both Oregon and Washington and to extend outward to the continental shelf.

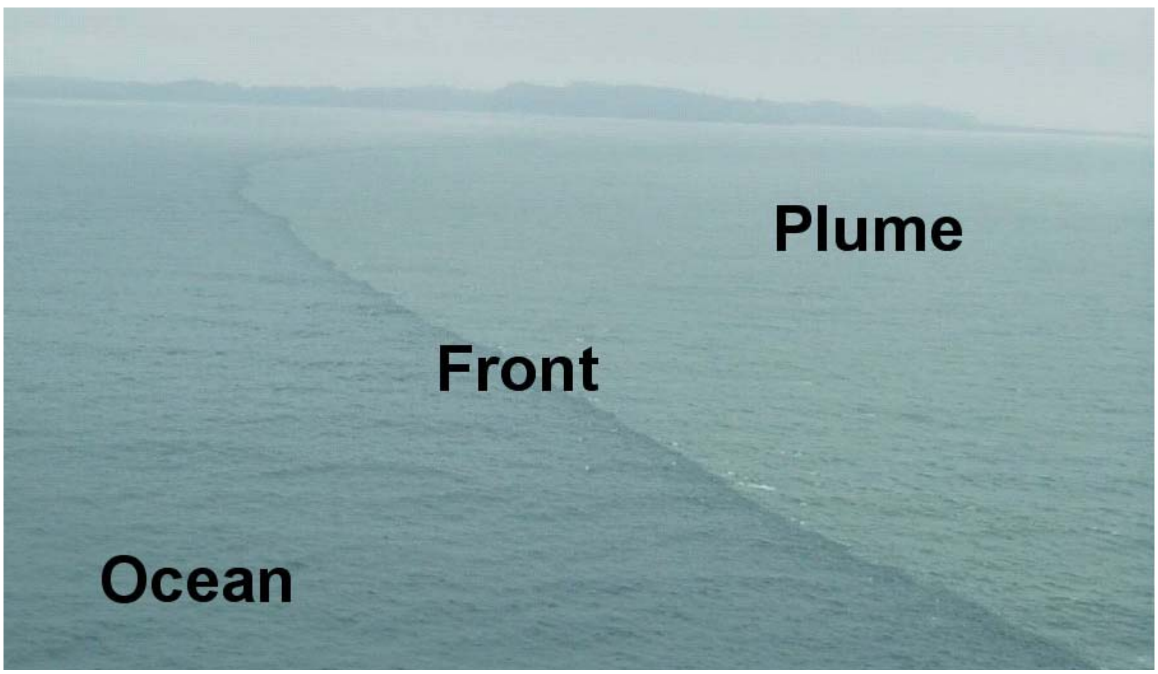

FIGURE 1-3
Plume Front
(Photo courtesy of NOAA Fisheries)

Major Land Uses

A variety of land uses are found adjacent to the Columbia River estuary. The area contains multiple cities and political jurisdictions, including Portland, which is Oregon's largest city, and Vancouver, the fourth largest Washington city. Other smaller cities include Astoria, Cathlamet, Longview, Kalama, Woodland, and Camas. Approximately 2.5 million people live in the vicinity of the estuary, and more are coming. Five deep-water ports in the area support a shipping industry that transports 30 million tons of goods annually (Lower Columbia Fish Recovery Board 2004), worth $13 billion each year (Columbia River Channel Improvement Reconsultation Project). Timber harvest occurs throughout the basin—six major pulp mills contribute to the region's economy. Until recently, aluminum plants along the river produced 43 percent of the country's aluminum. Agriculture is widespread throughout the floodplain and includes fruit and vegetable crops along with beef and dairy cattle. Commercial and recreational fishing activity plays an important role in local economies, bringing in millions of dollars of revenue each year. Primary outdoor recreational activities include fishing, wildlife observation, hunting, boating, hiking, and windsurfing.

Two Centuries of Change

Before Euro-American settlement of the Pacific Northwest, the Columbia River estuary and plume served as a physical and biological engine for salmon. Juveniles from hundreds of populations of steelhead, chum, chinook, and coho entered the estuary and plume every month of the year, with their timing honed over evolutionary history to make use of habitats rich with food. A beach seine survey during any month of the year would likely have yielded salmon of all species and many populations, with individuals of many sizes. This genetic variation in behavior was an important trait that allowed salmon and steelhead to occupy many habitat niches in time and space. It also guarded populations against catastrophic events such as volcanic eruptions (Bottom et al. 2005).

Today the Columbia River estuary and plume are much different. Notably, the North and South jetties at the mouth of the river restrict the marine flow of nutrients into the estuary. Dikes and levees lining the Washington and Oregon shores prevent access to areas that once were wetlands. New islands have been formed by dredged materials, and pile dikes reach across the river, redirecting flows. Less visible but arguably equally important are changes in the size, timing, and magnitude of flows that, 200 years ago, regularly allowed the river to top its banks and provide salmon and steelhead with important access to habitats and food sources. Flow factors, along with ocean tides, are key determents of habitat opportunity and capacity in the estuary and plume.

Salmon thrived in the Columbia River for 4,000 years. In the last 100 years, the entire Columbia River has undergone tremendous change as a direct result of people living and working in the basin. While the threats to salmon persistence are very diverse, at some level it is the increase in human population in the Northwest that underlies every human threat. There are an estimated 5 million people in the Columbia River basin today, and somewhere between 40 million and 100 million people are predicted to be living in the region by the end of the twenty-first century (National Research Council 2004). If we want healthy salmon runs at the same time that our population is multiplying, our interactions with land and water must pose fewer threats to salmonids than they have in the last 100 years. Before identifying management actions that could do just that, this document discusses which salmonids currently use the Columbia River basin, and how.

CHAPTER 2

Salmonid Use of the Estuary and Plume

The estuary and plume provide salmonids with a food-rich environment where they can undergo the physiological changes needed to make the transition from freshwater to saltwater habitats, and vice versa. Every salmonid that spawns in the Columbia River basin undergoes such a transformation twice in its lifetime—the first time during its first year of life (or soon after) when migrating out to sea, and the second time 1 to 3 years later, as an adult returning to spawn. The transition zone where juvenile salmonids undergo this transformation is thought to extend from the estuary itself to the near-shore ocean and plume habitats and into rich upwelling areas near the continental shelf (Casillas 1999).

The estuary and plume also serve as rich feeding grounds where juveniles have the opportunity for significant growth as they make the important transition from freshwater to seawater. Studies have shown that juvenile salmon released within the estuary and plume returned as larger adults and in greater numbers than juveniles released outside the transition zone (Casillas 1999). Thus, although juvenile salmonids face risks from a variety of threats in the estuary and plume (see Chapter 4), these environments can be highly beneficial. In the salmon life cycle, successful estuarine and plume residency by juveniles is critical for fast growth and the transition to a saltwater environment.

Clearly, the Columbia River estuary and plume are uniquely important to salmonids, and conditions in the estuary and plume undoubtedly affect salmonid survival. Yet the estuary and plume represent just one in a series of ecosystems that salmon use in their complex life cycle. Exploring the connections among these ecosystems, the habitats they provide, the salmonid species that use them, and the variety of life histories those salmonids display sheds further light on the role of the estuary and plume in the salmonid life cycle.

Salmonid Species in the Columbia River Basin

Before Euro-American settlement, the Columbia River basin was used extensively by six species of the family Salmonidae and the genus *Oncorhynchus*: chinook, chum, coho, and sockeye salmon plus two trout species: steelhead and sea-run cutthroat (Lichatowich 1999). Within these six species, 13 evolutionarily significant units (ESUs), representing more than 150 populations of salmon and steelhead, have been listed as threatened or endangered under the federal Endangered Species Act (Bottom et al. 2005). All 13 of the ESUs use the estuary and plume as an essential link in their far-reaching life cycles.

It is estimated that historically up to 16 million salmon from perhaps hundreds of distinct populations returned to the Columbia River each year (Lichatowich 1999). This contrasts markedly with recent returns of salmon and steelhead adults, which number approximately 1.25 million. To achieve these returns, an estimated 200 million juveniles are produced each year, approximately 50 to 95 percent of which are of hatchery origin, depending on the species (Bottom et al. 2005 as cited in Columbia Basin Fish and Wildlife Authority 1990 and Genovese and Emmett 1997).

Life History Types and Strategies

In discussing salmonids, fish scientists commonly refer to ocean type and stream type to distinguish two main freshwater rearing strategies. Ocean-type salmonids are characterized by migration to sea early in their first year of life, after spending only a short period rearing in freshwater (Fresh et al. 2005). Conversely, stream-type salmonids are characterized by migration to sea after rearing for more extended periods in freshwater, usually at least 1 year (Fresh et al. 2005). Table 2-1 shows the general characteristics of ocean-type and stream-type ESUs.

TABLE 2-1
Characteristics of Ocean- and Stream-Type Salmonids

Attribute	Ocean-Type Fish: fall chinook, chum	Stream-Type Fish: Coho, spring chinook, steelhead
Residency time	Short freshwater residence Longer estuarine residence Longer ocean residence	Long freshwater residence (>1 year) Shorter estuarine residence Shorter ocean residence
Size at estuary entry	Smaller	Larger
Primary habitat use	Shallow-water estuarine habitats, especially vegetated ones	Deeper, main-channel estuarine habitats; use plume more extensively

Adapted from Fresh et al. 2005.

In the Columbia River estuary, both ocean- and stream-type salmonids experience significant mortality. However, because the two types typically spend different amounts of time in the estuary and plume environments, they are subject to somewhat different combinations of threats and opportunities.

For ocean-type juveniles, mortality is believed to be most closely related to lack of habitat, changes in food availability, and the presence of contaminants. Stream types are affected by these same factors, although presumably to a lesser degree because of their shorter residency times in the estuary. However, stream types are particularly vulnerable to bird predation in the estuary because they tend to use the deeper, less turbid channel areas located near habitat preferred by piscivorous birds. Also, stream-type salmonids are thought to use the low-salinity gradients of the plume to achieve growth and gradually acclimate to saltwater. Changes in flow and sediment delivery in the plume may affect stream-type juveniles in a way similar to how estuary conditions affect ocean-type juveniles; however, additional research is needed to determine more precisely how stream types use the plume.

Fish scientists also describe salmonids in terms of the life history strategies they employ, meaning a population’s unique pattern of preferred spawning substrate, habitat use, migration timing, length of estuarine and marine residency, and so on. For thousands of years, Columbia River salmonids exhibited great diversity in life history strategies, exploiting every habitat niche available to them. This rich diversity in life history strategies allowed salmonids to persist as species for millennia even when individual populations were wiped out by disease or natural disturbances such as volcanic eruptions.

Table 2-2 identifies the six basic life history strategies used by salmon and steelhead in the Columbia River and their general attributes.

TABLE 2-2
Life History Strategies and Their Attributes

Life History Strategy	Attributes
Early fry	Freshwater rearing: 0 - 60 days Size at estuarine entry: <50 mm Time of estuarine entry: March - April Estuarine residence time: 0 - 40 days
Late fry	Freshwater rearing: 20 - 60 days Size at estuarine entry: <60 mm Time of estuarine entry: May - June, present through Sept. Estuarine residence time: <50 days
Early fingerling	Freshwater rearing: 60 - 120 days Size at estuarine entry: 60 - 100 mm Time of estuarine entry: April - May Estuarine residence time: <50 days
Late fingerling	Freshwater rearing: 50 - 180 days Size at estuarine entry: 60 - 130 mm Time of estuarine entry: June - October, present through winter Estuarine residence time: 0 - 80 days
Subyearling (smolt)	Freshwater rearing: 20 - 180 days Size at estuarine entry: 70 - 130 mm Time of estuarine entry: April - October Estuarine residence time: <20 days
Yearling	Freshwater rearing: >1 year Size at estuarine entry: >100 mm Time of estuarine entry: February - May Estuarine residence time: <20 days

Adapted from Fresh et al. 2005.

Changes in Life History Diversity

The 13 ESUs in the Columbia River express much less diversity in life history strategies now than they did historically. Formerly, both ocean- and stream-type salmonids entered the estuary and plume throughout the year, at a great variety of sizes, which reflected the various life history strategies in Table 2-2. Today juveniles tend to arrive in pulses and are more uniform in size.

TABLE 2-3
Linkage between Salmonid ESU, Dominant Life History Type, and Life History Strategy

ESU	Life History Type	Historical and Current Life History Strategies					
		Early Fry	Late Fry	Early Fingerling	Late Fingerling	Sub-yearling	Yearling
Columbia River chum salmon	Ocean	Abundant	Abundant	Absent	Absent	Absent	Absent
Snake River sockeye salmon	Stream	Absent	Absent	Absent	Absent	Rare	Abundant
Lower Columbia River coho salmon	Stream	Historically rare, currently absent	Historically rare, currently absent	Historically rare, currently absent	Historically rare, currently absent	Rare	Abundant
Upper Columbia River steelhead	Stream	Absent	Absent	Absent	Absent	Historically rare, currently absent	Abundant
Snake River steelhead	Stream	Absent	Absent	Absent	Absent	Historically rare, currently absent	Abundant
Lower Columbia River steelhead	Stream	Absent	Absent	Absent	Historically rare, currently absent	Historically medium, currently rare	Abundant
Middle Columbia River steelhead	Stream	Absent	Absent	Historically rare, currently absent	Historically rare, currently absent	Historically medium, currently rare	Abundant
Upper Willamette River steelhead	Stream	Absent	Absent	Absent	Absent	Historically rare, currently absent	Abundant
Snake River fall chinook salmon	Ocean	Absent	Absent	Historically medium, currently rare	Historically medium, currently rare	Abundant	Historically rare, currently medium
Upper Willamette River chinook salmon	Ocean	Historically rare, currently absent	Historically rare, currently absent	Historically medium, currently rare	Historically medium, currently rare	Rare Medium	Abundant
Lower Columbia River fall chinook salmon	Ocean	Medium Rare	Medium Rare	Historically medium, currently rare	Historically medium, currently rare	Medium Abundant	Rare
Upper Columbia River spring chinook salmon	Stream	Absent	Absent	Historically rare, currently absent	Historically rare, currently absent	Rare	Abundant
Snake River spring/summer chinook salmon	Stream	Absent	Absent	Historically rare, currently absent	Historically rare, currently absent	Rare	Abundant

Adapted from Fresh et al. 2005.

Table 2-3 shows losses in life history diversity in the Columbia River. The table identifies the dominant life history type (ocean vs. stream) and strategies for each ESU, the prevalence of each life history strategy, and whether that prevalence has changed from historical times to the present. The number of life history strategies employed by some ESUs, such as Columbia River chum, have not changed. But for other ESUs—notably the Lower Columbia River coho—several life history strategies that use to exist have been lost.

Losses in life history diversity can also be seen in Figure 2-1, which compares historical and current estuarine life history types for one brood year of chinook salmon. The figure shows a reduction in the number of strategies available in the contemporary versus historical estimates.

Some of the losses in salmonid life history diversity are attributable to habitat alterations throughout the Columbia River basin that have eliminated entire populations of salmon and steelhead. In other cases, hatcheries and harvest impacts have reduced the health and genetic makeup of species. As a result, many of the populations currently using the estuary and plume are significantly different than the fish that historically used the various habitats available to them, and some existing habitats may not be being used by salmonids at all.

Relationship of the Estuary to the Columbia River Basin

Scientists working at NOAA's Northwest Fisheries Science Center have recently published a technical memorandum that establishes an ecologically based conceptual framework for understanding the estuary within the larger context of the Columbia River basin. In *Salmon at River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon*, Bottom et al. (2005) hypothesize that Columbia River salmon's resilience to natural environmental variability is embodied in population and life history diversity, which maximizes the ability of populations to exploit available estuarine rearing habitats. The conceptual framework is based on Sinclair's (1988) member/vagrant theory, which proposes general principles for understanding marine species with complex life cycles.

Bottom et al. (2005) hypothesize that how an individual salmon or steelhead uses the ecosystems it encounters—when juveniles migrate, how big they are, what habitat they use, and how long they stay in a particular habitat—correlates directly to the discrete population of fish that individual is part of. In other words, different populations within ESUs employ different life history strategies. For example, two populations of steelhead within an ESU may produce juveniles of different sizes that enter the estuary at different times, and these juveniles may use distinct habitats that may be available only at that particular time.

Considering that the estuary is just one of three major ecosystems used by salmon and steelhead, the member/vagrant theory implies that how juveniles migrate and use estuarine habitat may depend as much on the status of upriver habitats and corresponding populations as on environmental conditions in the estuary itself (Bottom et al. 2005). That is, if there is a close relationship between particular geographical features in the estuary and the life history of a discrete salmonid population, use of the estuary may reflect the abundance and life history strategy of the associated population, which is in part a function of upstream conditions. Thus, if salmonid migration and rearing behaviors in the estuary are linked to specific geographic features and those features are reduced or eliminated, mortality in the population that uses those features increases (Bottom et al. 2005). By the same token, if salmonid populations are lost because of other factors (such as blockage by dams), habitats in the estuary may be left unoccupied.

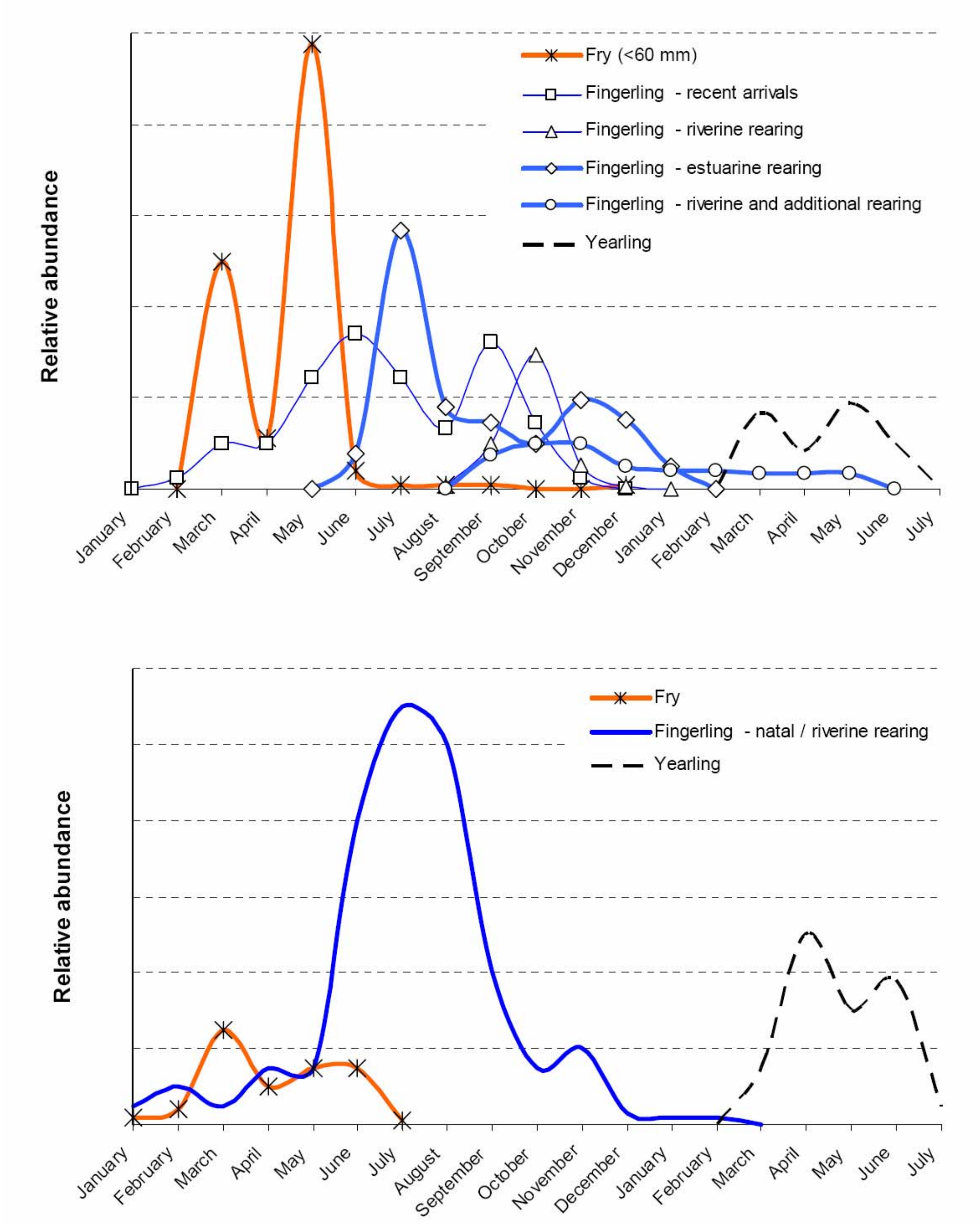

FIGURE 2-1
Historical and Contemporary Early Life History Types of Chinook Salmon in the Columbia River Estuary
(Reprinted from Fresh et al. 2005.)

The implication for salmon recovery in the Columbia River basin is that habitat use by salmonids must be considered from a multi-ecosystem perspective if we are to understand which components of each ecosystem—tributaries, mainstem, estuary, plume, nearshore, and ocean—are limiting the overall performance of salmon.

Summary

Since 1991, 13 Columbia River ESUs have been listed as threatened or endangered under the federal Endangered Species Act. During their complex life cycles, listed salmon and steelhead rely on many diverse ecosystems, from tributaries to ocean environments, that span hundreds or thousands of miles. For recovery efforts to be successful, it is necessary to understand salmonids' requirements during all stages of their life cycles. Thus, although the estuary and plume represent important stages in the salmonid life cycle, these ecosystems must be considered within the context of other life cycle stages if management actions are to be effective. Perhaps most central to the recovery of listed ESUs is the importance of conserving biological diversity and the native ecosystems it depends on (Bottom et al. 2005).

CHAPTER 3

Limiting Factors

Chapter 3 identifies and prioritizes the key physical, chemical, or biological features impeding ESUs and their independent populations from reaching viability status. These features are referred to as limiting factors. The discussion of limiting factors in this chapter pertains to the estuary and plume; however, upstream limiting factors in some cases have a direct bearing on conditions in the estuary.

Determining Estuary Habitat Limiting Factors

Sources

For this estuary recovery module, limiting factors were identified and prioritized based on a thorough review and synthesis of pertinent literature, supplemented by input from area experts that included staff from NOAA's Northwest Fisheries Science Center and Portland office, the Lower Columbia River Estuary Partnership, and the Lower Columbia Fish Recovery Board. Several key documents provided consistent guidance. They included the following:

- *Salmon at River's End: The Role of the Estuary in the Decline and Recovery of Columbia River Salmon* (Bottom et al. 2005)—NOAA technical memorandum
- *Role of the Estuary in the Recovery of Columbia River Basin Salmon and Steelhead: An Evaluation of the Effects of Selected Factors on Salmonid Population Viability* (Fresh et al. 2005)—NOAA technical memorandum
- *Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan* and its supplement—Lower Columbia River Estuary Partnership (2004a)

These three literature sources, and others, identified and prioritized limiting factors in a similar manner. But it should be noted that the three sources have separate goals, and this affects each document's structure and content. Thus, the depth and breadth of information were not always consistent across documents.

Mortality Estimates

Estimates of salmon and steelhead mortality in the estuary and mainstem are not well supported in the literature; however, some modeling efforts have made assumptions about estuary mortality. One example is Ecosystem Diagnosis and Treatment (EDT), a life-cycle model that accounts for the estuarine stage of salmon and steelhead in tributaries of the Columbia River. For lower Columbia River ESUs, EDT assumes 18 to 58 percent mortality for various populations. There are, however, more reliable mortality estimates for a few limiting factors. For example, Caspian tern predation is estimated to be responsible for about 5.9 million smolts each year (Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers 2004). If this estimate is accurate, tern predation results in the mortality of nearly 3 percent of the Columbia River basin smolt production.

The Caspian tern example is the exception rather than the rule. In most cases it is very difficult to point to a specific limiting factor and then estimate mortality. This is because of the inherent complexity associated with connecting the physical, chemical, and biological features that limit the productivity of salmon and steelhead.

Density Dependence

One potential limiting factor that is not included in this chapter's identification and prioritization of limiting factors is density dependence, which refers to competition among hatchery and naturally produced fish. There is growing awareness among scientists studying the Columbia River estuary that mechanisms related to density dependence may limit salmon and steelhead while they are using estuary and plume habitats. The principle is simple: It is possible that too many fish are competing for limited habitat and associated resources in the estuary at key times, and that the resulting stressors translate into reduced salmonid survival. Density dependence can occur at any stage in the salmon and steelhead life cycle.

Scientists studying Skagit River fall chinook have documented density dependence-related mortality as a result of loss of habitat in the Skagit estuary and believe that such mortality can be attributed to a 75 percent loss of tidal delta estuarine habitat (Beamer et al. 2005). With similar habitat losses in the Columbia River estuary, NOAA's Northwest Fisheries Science Center is currently investigating potential density dependence mortality there, and results should be available soon. The *Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan* raised the specter of density dependence in the estuary and recommended continued research to analyze conditions there (Lower Columbia River Estuary Partnership 2004a). Thus, although the occurrence of density dependence-related mortality in the Columbia River estuary has not been proven, given the dramatic changes in habitat opportunity and capacity that have occurred in the estuary over the last 200 years, the question lingers.

Habitat-Related Limiting Factors

Salmonid populations exhibit diverse strategies that guide them through various habitats and ecosystems in specific sequences and patterns. If those sequences and patterns are interrupted, increased mortality may result. Thus, mismatches between the needs of salmon populations and the availability of habitats to meet those needs can limit salmon performance in the estuary and plume. The member/vagrant theory discussed in Chapter 2 underscores the need to consider relationships between ESUs' life history strategies and the quality, quantity, and availability of habitats in the estuary and other ecosystems that are interconnected via the salmon and steelhead's complex life cycle.

The habitats that salmonids occupy during their residency in the estuary and plume are formed through the interaction of ocean forces, land, and river flow (Fresh et al. 2005). Flows entering the estuary govern the general availability of habitats, along with sediment transport, salinity gradients, and turbidity, which are themselves aspects of habitat or habitat formation. Over the last 200 years, the magnitude, timing, and frequency of flows have changed significantly, with corresponding effects on the formation and availability of salmonid habitats. Some habitat has been removed, which has reduced the total acreage of the estuary by approximately 20 percent (Fresh et al. 2005). In other cases, particular habitat types have been transformed to other habitat types, and the resulting mosaic of habitats may not be meeting the needs as salmonids as well as the historical pattern of habitats did. For example, approximately 77 percent of historical tidal swamp has been lost (Lower Columbia River Estuary Partnership 2004a), while other shallow-water habitats have increased significantly. The loss of tidal swamps and other forested or vegetated wetlands represents a loss of habitat that ocean-type salmonids use during their estuarine residence. In short, habitat opportunity and capacity have been degraded in the estuary and plume, and alterations in flow have contributed significantly to losses in in-channel, off-channel, and plume habitat.

Affected salmonids: Because of their longer estuary residence times and tendency to use shallow-water habitats, ocean-type ESUs are more affected by flow alterations that structure habitat and/or provide access to wetland or floodplain areas than are stream-type ESUs. Stream types have relatively short estuary residence times and use the plume much more extensively than ocean types do. Thus stream-type salmonids are affected by habitat elements such as the shape, behavior, size, and composition of the plume (Fresh et al. 2005).

Reduced In-Channel Habitat Opportunity

In-channel habitat opportunity in the estuary is a function of the size of river flows, the timing of river flows, incoming and outgoing tides, and the amount and patterns of sediment accretion. Together, tidal action, river flow, and sediment movement create a constantly changing mosaic of channel habitats as water levels rise and fall, sands shift, and salinity gradients move in response to tides. To support salmonids, the various habitats in the estuary need to be connected both spatially and in time. With twice-daily tidal changes, areas that may be accessible at one point during the day may be inaccessible 6 hours later because of tidal fluctuations. Changes in both flow and sediment transport have reduced in-channel habitat opportunity.

Limiting Factor: Flow-Related Estuary Habitat Changes. The ability of juvenile salmon to access and benefit from habitat depends greatly on instream flow (Fresh et al. 2005). Changes in the quantity and seasonality of flows in the estuary have a direct bearing on whether key habitats are available to salmonids, when those habitats are available, and whether and how they connect with other key habitats. In addition, juvenile salmonids have physiological or behavioral traits that set the timing for their transformation to saltwater, and changes in flows may interrupt this timing.

Both the quantity and timing of instream flows entering the Columbia River estuary and plume have changed from historical conditions (Fresh et al. 2005). Jay and Naik (2002) reported a 16 percent reduction of annual mean flow over the past 100 years and a 44 percent reduction in spring freshet flows. Jay and Naik also reported a shift in the hydrograph to 14 to 30 days earlier in the year, meaning that spring freshets are occurring earlier in the season. In addition, the interception and use of spring freshets (for irrigation, reservoir storage, etc.) have caused increased flows during other seasons (Fresh et al. 2005). These changes in the Columbia River hydrograph are limiting factors for salmon and steelhead and have affected habitat opportunity and capacity in the estuary and plume.

Limiting Factor: Sediment-Related Estuary Habitat Changes. The transport of sediment is fundamental to habitat-forming processes in the estuary through sediment deposition and erosion (Fresh et al. 2005). Sediment from the estuary and upstream sources also affects the formation of near-shore ocean habitats north and south of the Columbia River entrance.

Since the late nineteenth century, sediment transport from the interior basin to the Columbia River estuary has decreased about 60 percent and total sediment transport has decreased about 70 percent (Jay and Kukulka 2003). This reduction in the amount of sediment transport in the Columbia River has affected habitat-forming processes in the estuary and plume (Bottom et al. 2005) and is presumed to be a limiting factor for salmon and steelhead. Although the consequences of the reduced transport of sediment through the estuary and plume are not fully understood, the magnitude of change is very large compared to historical benchmarks (Fresh et al. 2005).

Reduced Off-Channel Habitat

Columbia River access to its historical floodplain is an important factor for rearing ocean-type juvenile salmonids. Historically, flows that topped the river's bank provided juvenile salmonids with access to low-velocity areas they used as refugia and for rearing. Overbank flows also contributed key food web inputs to the ecosystem and influenced wood recruitment, predation, and competition in the estuary (Fresh et al. 2005).

Today, mainstem habitat in the Columbia and Willamette rivers has been reduced to a single channel (Lower Columbia River Estuary Partnership 2004a), and channelization of the estuary has eliminated access to an estimated 77 percent of historical tidal swamps (Fresh et al. 2005). In fact, over the past 200 years the surface area of the estuary has decreased by approximately 20 percent (Fresh et al. 2005).

The near elimination of overbank flooding is a function of both reductions in flow volume and increases in the bankfull level of the Columbia River, among other factors.

Figure 3-1 shows diked areas from the estuary mouth to Bonneville dam. This map was generated from a new Lower Columbia River Estuary Partnership GIS database that is currently under development. In early 2006, new GIS layers will provide state-of-the-art statistics and maps depicting the historical floodplain, diked areas, dredged material disposal sites, over-water structures, contaminant monitoring sites, and other key features in the estuary.

Limiting Factor: Flow-Related Changes in Access to Off-Channel Habitat. Reduced access to off-channel habitats is a limiting factor for salmon and steelhead because of impacts on food webs and the reduced availability of habitats preferred by fry and fingerlings. Typically, overbank flows were driven by spring freshets, which occurred at the time of year when there was the greatest variety of juvenile salmon and steelhead using the estuary (Fresh et al. 2005). Overbank flows occur much less frequently now than they did historically, in part because climate changes and human alterations have reduced the number of high flows in the Columbia (Jay and Kukulka 2003).

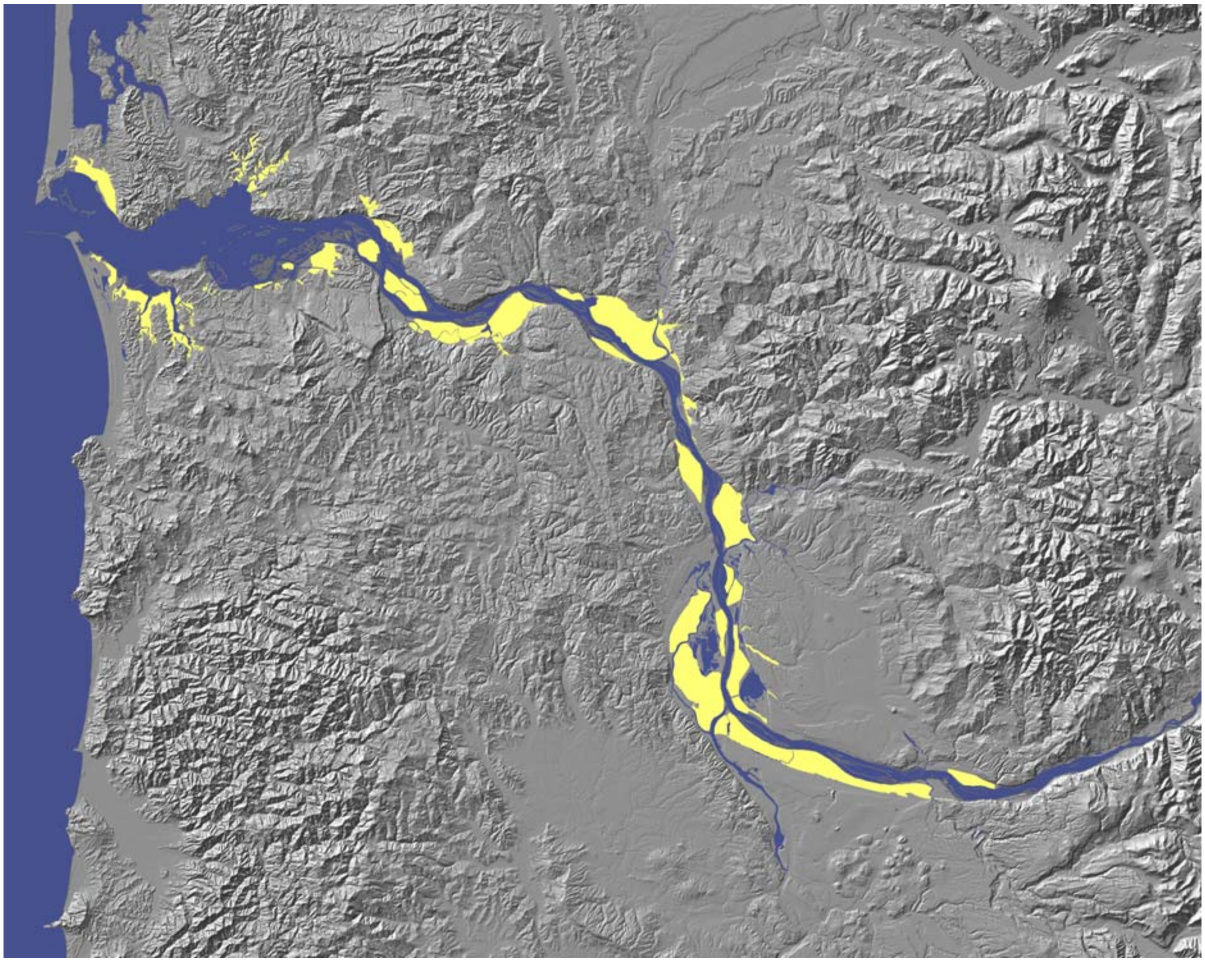

FIGURE 3-1
Diked Areas in the Columbia River Estuary

Limiting Factor: Bankfull Elevation Changes. The construction of levees also has reduced the frequency of overbank flows because more river water is needed to cause overbank flow. Historically the bankfull level was 18,000 $m^3 s^{-1}$, while today it is 24,000 $m^3 s^{-1}$—fully one-third more. Only five overbank events have occurred since 1948 (Jay and Kukulka 2003). The reduction in overbank events is a limiting factor because it reduces the availability of food and refugia for ocean-type juveniles rearing in the estuary. Less dominant stream-type juveniles are affected in the same manner.

Reduced Plume Habitat Opportunity

Evidence suggests that the plume supports ocean productivity by increasing primary plant production during the spring freshet period, distributing juvenile salmonids in the coastal environment, concentrating food sources such as zooplankton, and providing refugia from predators in the more turbid, low-salinity plume waters (Fresh et al. 2005). Changes in the Columbia River hydrograph have altered both the size and structure of the plume during the spring and summer months (Northwest Power and Conservation Council 2000).

Limiting Factor: Flow-Related Plume Changes. For juvenile salmonids preparing for ocean life, the plume is believed to function as habitat, as a transitional saltwater area, and as refugia. As mentioned earlier, stream-type ESUs in particular are affected by the size, shape, behavior, and composition of the plume (Fresh et al. 2005).

Over the past 200 years characteristics of the plume have been altered, and conditions caused by reductions in spring freshets and associated sediment transport processes may now be suboptimal for juvenile salmonids (Casillas 1999). Plume attributes affected by changes in flow include surface areas of the plume, the volume of the plume waters, the extent and intensity of frontal features, and the extent and distance offshore of plume waters (Fresh et al. 2005).

Limiting Factor: Sediment/Nutrient-Related Plume Changes. It is believed that the sediment and nutrients transported in the plume fuel ocean productivity and provide relief from predation (Casillas 1999). This is particularly true for stream-type ESUs, who use the plume more extensively than ocean types do and thus are more affected when the amount of plume habitat is reduced.

Limiting Factor: Stranding

In the estuary, large ships passing through the navigational channel produce bow waves that crash against shorelines in Oregon and Washington. Small ocean-type fry and fingerlings rear within inches of shore and may become stranded as waves intersect the bank and recede (Ackerman 2002), although the extent of this problem is unclear. A 1977 study by the Washington Department of Fisheries (WDF) estimated that more than 150,000 juvenile salmonids—mostly chinook—were stranded on five test sites (Bauersfeld 1977).

A NOAA technical memorandum (Hinton and Emmett 1994) published in 1994 concluded that the problem was not as significant as documented in the WDF report. An upcoming report by the University of Washington and Portland District of the U.S. Army Corps of Engineers may provide a clearer picture of the magnitude of the impact.

Food Web-Related Limiting Factors

Energy released from the Columbia River and the ocean converges in the estuarine, near-shore ocean, and plume environments where, combined with the biological energy of primary plant production, it forms the basis for life in the estuarine ecosystem. Ultimately, energy for the ecosystem begins with sunlight, sunlight leads to plant growth, plants are eaten by animals, and animals eat each other. Energetic processes, then, determine what is being eaten and by whom.

For the past 4,000 years, salmon and other native species have evolved together in response to the basic inputs of energy and their circulation through the ecosystem. The result has been the development of an intricately structured food web in the estuary that encompasses food sources, food availability, and inter- and intra-species relationships. Although stable ecosystems go through cycles of change in energy flows over time, basic energy pathways frequently remain unaltered. As the flow of energy through the ecosystems changes, so do the relationships among species and between species and their habitats. Competition and predation relationships shift and the abundance of species increases or decreases, depending on species' ability to adapt to changing conditions. Changes in any one of the elements of the food web, such as food sources or availability, can ripple throughout the ecosystem and have potentially far-reaching effects on salmonids and other species.

As part of the food web, plant materials known as detritus are consumed by juvenile salmonids, either directly or indirectly through other organisms that feed on the detritus (Lower Columbia River Estuary Partnership 2004a). There is evidence that a shift in plant primary production in the estuary—from a macrodetrital to a microdetrital base—has significantly changed the food web and that complex inter- and intra-species relationships have been permanently altered (Lower Columbia River Estuary Partnership 2004a). Food web-related conditions that may have reduced the productive capacity of the estuary include reduced foraging habitat, changes in detrital sources, and fine sediment inputs. By disrupting the food web, these conditions have increased competition and predation (Bottom et al. 2005).

Insects also may play a crucial role in maintaining the food web. A recent University of Washington master's thesis demonstrated the importance of midge insects in the diet of juvenile chinook salmon occupying shallow-water habitats in the Columbia River estuary—emerging chironomids were the dominant prey for chinook of all sizes (Lott 2004). The importance of flora that support insect availability in emergent marsh, scrub-shrub wetland, and forested wetlands used by salmonids with ocean-type life history strategies is likely to become an area of greater interest by scientists.

Affected salmonids: Ocean-type ESUs are more likely than stream-type juveniles to be affected by food web alterations because of their use of estuary habitats and their longer residency times. Stream-type ESUs are more influenced in the plume environment because of reduced fine-sediment inputs leaving the estuary.

Food Source Changes

As described below, changes in the detrital sources that form the base of the estuarine food web have been significant and represent a limiting factor for salmonids. Figure 3-2 shows a conceptual model of the estuary food web developed by the U.S. Army Corps of Engineers. The historical tidal marsh macrodetritus-based food web is displayed at the top of Figure 3-2, while the current food web, which is based on imported microdetritus, is shown at the bottom.

Limiting Factor: Reduced Macrodetritus Inputs. The estuarine food web formerly was supported by macrodetrital inputs of plant materials that originated from emergent, forested, and other wetland rearing areas in the estuary (Lower Columbia River Estuary Partnership 2004a). Today, detrital sources from emergent wetlands in the estuary are approximately 84 percent less than they were historically (Bottom et al. 2005).

Macrodetritus plant production has declined as a result of the construction of revetments along the estuary shorelines, the disposal of dredged material in what formerly were shallow or wetland areas where plant materials or insects could drop into the water, and reductions in flow. Flow reductions affect detrital sources by limiting the amount of wetlands—areas that normally would be contributing microdetritus to the food web—and cutting the number of overbank flows. Historically, much of the detrital inputs occurred during overbank events, which provided additional shallow-water habitat for juvenile salmonids and resulted in significant detrital inputs to the estuary. As mentioned earlier, overbank events occur much less frequently today than they did historically.

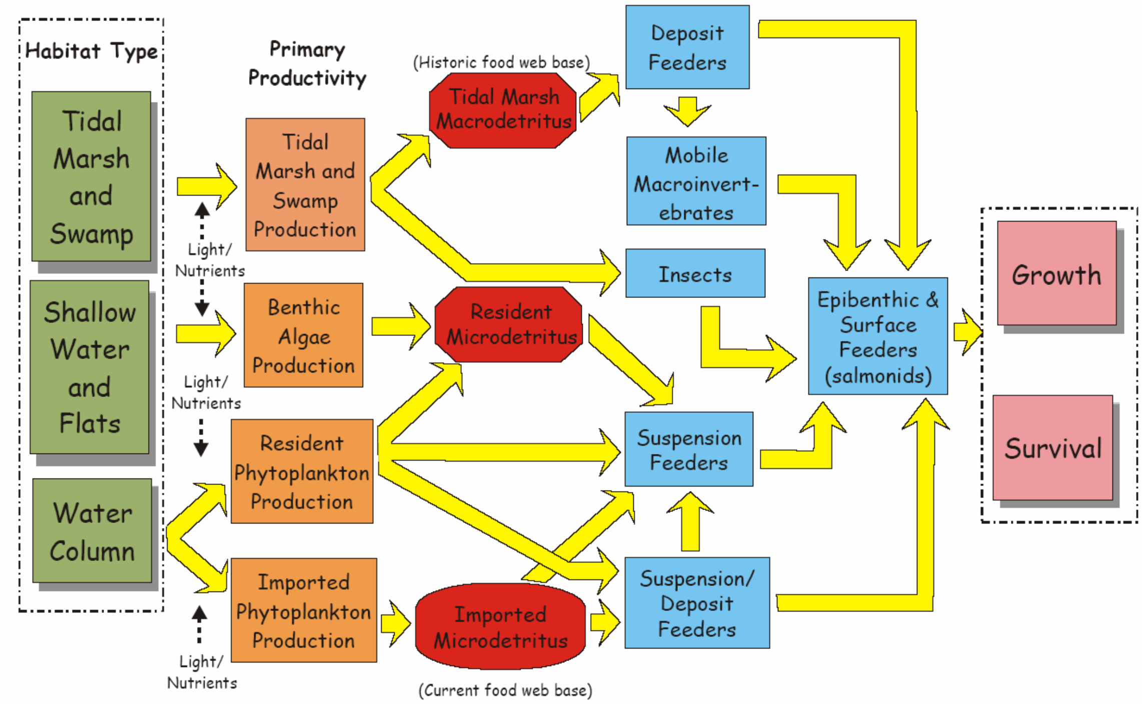

FIGURE 3-2
Conceptual Model of the Columbia River Estuary Food Web

Limiting Factor: Increased Microdetritus Inputs. Instead of being supported by local plant production, the current food web is based on decaying phytoplankton delivered from upstream reservoirs. The amount of this microdetritus has increased dramatically (Bottom et al. 2005). The switch in primary production in the estuary from a macrodetritus-based source to a microdetritus-based source has lowered the productivity of the estuary (Bottom et al. 2005).

The substitution of detrital sources in the estuary also has contributed to changes in the spatial distribution of the food web (Bottom et al. 2005). Historically the macrodetritus-based food web was distributed evenly throughout the estuary, including in the many shallow-water habitats favored by ocean-type salmonids. But the contemporary microdetrital food web is concentrated within the estuarine turbidity maximum in the middle region of the estuary (Bottom et al. 2005). This location is less accessible to ocean-type ESUs that use peripheral habitats and more accessible to species such as American shad that feed in deep-water areas.

Pelagic fish such as shad may also benefit from the fact that the estuarine turbidity maximum traps particles and delays their transport to the ocean up to 4 weeks, compared to normal transport of around 2 days (Lower Columbia River Estuary Partnership 2004a). The estuarine turbidity maximum is thought to contain bacteria that attach to detritus. Together these represent the primary food source in the estuary today (Lower Columbia River Estuary Partnership 2004a).

Competition and Predation

Predation and competition for habitat and prey resources limit the success of juvenile salmonids entering the estuary and plume. Both spatial and energetic losses can involve either density-dependent or density-independent processes (Bottom et al. 2005). Spatial and temporal losses of habitat and large pulses of hatchery juveniles may, under some conditions, result in density-dependent salmonid mortality (Bottom et al. 2005). Emerging studies in the Skagit River are predicting density-dependent losses to juvenile salmonids in the river delta (Beamer et al. 2005).

Competition among salmonids and between salmonids and other fish may be occurring in the estuary, with the intensity and magnitude of competition depending in part on how long hatchery and natural juvenile salmonids reside in the estuary (Lower Columbia Fish Recovery Board 2004). When large numbers of ocean-type salmonids enter the estuary, it may become overgrazed. Food availability may be reduced as a result of the temporal and spatial overlap of juveniles from different locations, including hatcheries (Lower Columbia Fish Recovery Board 2004 as cited in Bisbal and McConnaha 1998).

Ecosystem-scale changes in the estuary have altered the relationships between salmonids and other fish, birds, and mammals species, both native and exotic. Some native species' abundance levels have decreased from historical levels—perhaps to the point of extinction—while others have increased to levels far exceeding those in recorded history, with associated changes in predation of salmon and steelhead juveniles.

The presence of non-indigenous fish, invertebrates, and plants in species assemblages indicates major changes in aquatic ecosystems (Lower Columbia River Estuary Partnership 2004a). Globally the introduction of such species is increasing, a fact that is attributable to the increased speed and range of world trade, which facilitates the transport and release—whether intentional or not—of non-indigenous species (Lower Columbia River Estuary Partnership 2004a). In the estuary, the introduction of exotic species has altered the ecosystem through competition, predation, disease, parasitization, and alterations in the food web.

Non-native species affect ocean-type ESUs more than they do stream-type ESUs because of the ocean types' longer juvenile estuary residency times and use of shallow-water habitats.

Limiting Factor: Native Fish. The northern pikeminnow is a native piscivorous fish that preys on juvenile salmonids in the estuary. Although pikeminnows have always been a significant source of mortality for juvenile salmonids in the Columbia River, changes in physical habitats may have created more favorable conditions for predation (Lower Columbia River Estuary Partnership 2004a). The diet of pikeminnows varies with age, with the largest adults representing the biggest risk to juvenile salmonids. Ocean-type ESUs are affected more than stream-type ESUs because of their longer estuary residency times and use of shallow-water habitats.

Limiting Factor: Native Birds. As a result of estuary habitat modifications, the number and/or predation effectiveness of Caspian terns, double-crested cormorants, and a variety of gull species has increased (Fresh et al. 2005). In 1997 it was estimated that avian predators consumed 10 to 30 percent of the total estuarine salmonid smolt production in that year (Lower Columbia River Estuary Partnership 2004a). Stream-type juvenile salmonids are most vulnerable to avian predation by Caspian terns because the juveniles use deep-water habitat channels that have relatively low turbidity and are close to island tern habitats. Double-crested cormorants may consume a similar number of juveniles; however, their impacts are not well studied (Roby et al. 2002 as cited in Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers 2004).

Limiting Factor: Native Pinnipeds. The abundance of native pinnipeds has steadily increased since passage of the Marine Mammal Protection Act in 1972. Harbor seals, Steller sea lions, and California sea lions all prey on salmon and steelhead in the estuary (Lower Columbia River Estuary Partnership 2004a). Diet studies indicate that pinnipeds consume both juvenile and adult salmonids. Anecdotal evidence suggests significant mortality of adult salmon in the estuary and mainstem up to Bonneville Dam (Lower Columbia River Estuary Partnership 2004a). The impacts of pinniped predation on adult ocean- and stream-type salmonids are similar because most predation occurs on adults.

Limiting Factor: Exotic Fish. At least 37 exotic fish species are now found in the Columbia River estuary (Lower Columbia River Estuary Partnership 2004a). American shad have migrated to the Columbia River from the Sacramento River, and adult returns now exceed 4 million in a single year (Lower Columbia River Estuary Partnership 2004a). While shad do not eat salmonids, they exert tremendous pressure on the estuary food web given the sheer weight of their biomass. Other exotic fish in the estuary, such as smallmouth bass, walleye, and catfish, are piscivorous; however, their abundance levels are relatively small.

Limiting Factor: Introduced Invertebrates. Twenty-seven invertebrate species have been observed in the estuary and documented by the Lower Columbia River Aquatic Non-indigenous Species Survey (Sytsma et al. 2004). Recent surveys have documented that the estuarine copepod community has changed from a system dominated by a single introduced species, *Pseduodiaptomis inopinus*, to a system dominated by two newly introduced Asian copepods: *Pseudodiaptomis forbesi* and *Sinoclaanus doerri* (Santen 2004). In some cases, the abundance of invertebrates can alter food webs through their wide distribution and consumption of prey (Lower Columbia River Estuary Partnership 2004a).

Limiting Factor: Exotic Plants. The introduction of non-indigenous plant species also has altered the estuary ecosystem. Exotic plant species often out-compete native plants, which results in altered habitats and food webs (Lower Columbia River Estuary Partnership 2004a). About 18 aquatic plants have been introduced into the estuary since the 1880s (Sytsma et al. 2004). Examples of non-indigenous plant species include purple loosestrife, Eurasian milfoil, parrot feather, and Brazilian elodea. In addition to out-competing native plants, introduced plant species can contribute to poor water quality and create dense, monospecific stands that represent poor habitat for native species (Lower Columbia River Estuary Partnership 2004a). In turn, these new plant communities may alter insect and detritus production in and around vegetated wetlands.

Water Quality-Related Limiting Factors

Water quality issues in the Columbia River estuary influence the capacity of habitats to accommodate juvenile salmonids. Important water quality factors include temperature changes, dissolved oxygen levels, and the presence of various toxic contaminants. Historically, levels of contaminants in the Columbia River were low, except for some metals and naturally occurring substances (Fresh et al. 2005). Contaminant levels are much higher in the estuary today and are the result of upstream and estuary sources.

Limiting Factor: Temperature

Water temperatures of between 20° and 24° C are considered the upper range for cold-water species such as salmonids (National Research Council 2004). Alterations in water temperature affect the metabolism, growth rate, and disease resistance of salmonids, as well as the timing of adult migrations, fry emergence, and smoltification (Lower Columbia Fish Recovery Board 2004 as cited in National Marine Fisheries Service 2000).

Since 1938, summer water temperatures at Bonneville Dam have increased 4 degrees on average (Lower Columbia Fish Recovery Board 2004). Among-year variability in temperature has been reduced by 63 percent after 1970 (Lower Columbia Fish Recovery Board 2004). As shown in Figure 3-3, temperatures entering the estuary (as measured at Bonneville Dam) have steadily since 1938. Temperatures also exceed 20° C earlier during the year and more frequently than they did historically (National Research Council 2004).

Toxic Contaminants

The quality of habitats in the Columbia River estuary is degraded as a result of past and current releases of toxic contaminants (Fresh et al. 2005). Currently the estuary receives contaminants from more than 100 point sources and numerous non-point sources, such as surface and stormwater runoff from agricultural and urban sources (Fresh et al. 2005). With the cities of Portland, Vancouver, Longview, and Astoria on its banks, the Columbia River below Bonneville Dam is the most urbanized section of the river.

Sublethal concentrations of contaminants affect the survival of aquatic species by increasing stress, predisposing organisms to disease, delaying development, and disrupting physiological processes, including reproduction. In juvenile salmonids, contaminant exposure can result in decreased immune function and generally reduced fitness (Lower Columbia River Estuary Partnership 2004a).

A recent study by Loge et al. in the Columbia River will likely bring more attention to the effects of contaminants on salmonids in the estuary. The study documents infectious disease in outmigrating juvenile salmonids attributed to abiotic stressors, such as chemicals, that influence host susceptibility to infection. The study estimates delayed disease-induced mortalities in chinook salmon at 3 percent and 18 percent for estuary residence times of 30 to 120 days, respectively (Loge et al. 2005). Other contaminants in the water column, including endocrine-disrupting substances such as synthetic hormones, are only beginning to be characterized in the estuary, but these contaminants could have substantial effects on salmon and steelhead (Fresh et al. 2005).

The exposure of stream-type juveniles to contaminants in the plume is understudied. The Lower Columbia River Estuary Partnership currently is leading an effort to develop a model of contaminant flux in the estuary. The model will identify natural processes and anthropogenic perturbations that affect the estuarine environment. Initial products should be available early in 2006.

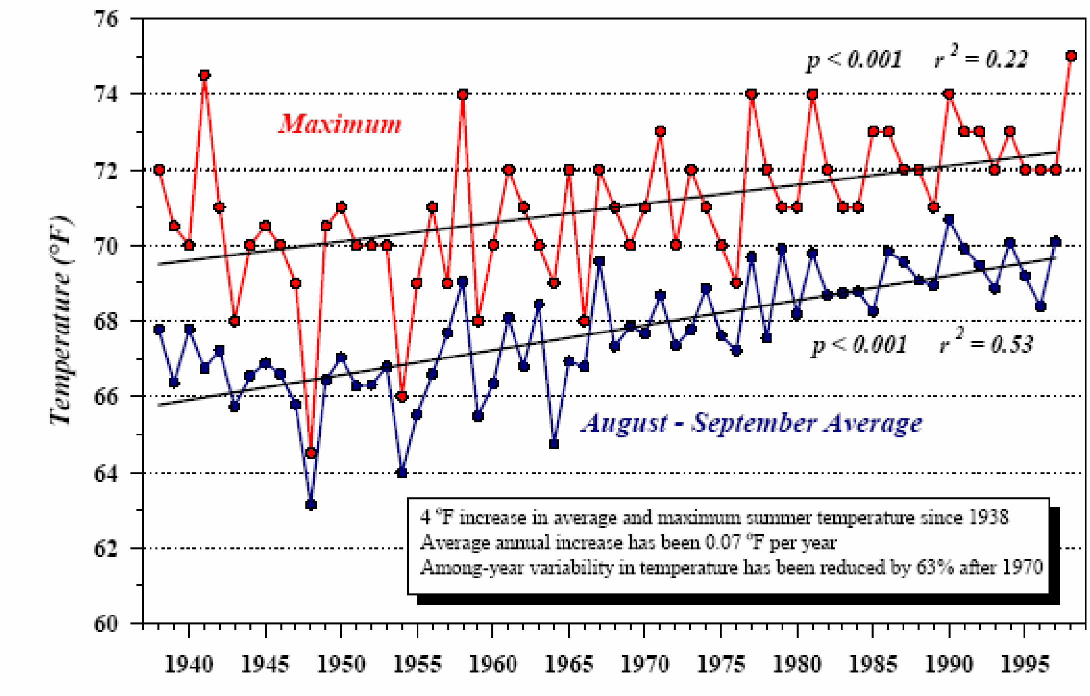

FIGURE 3-3
Temperatures of Water Entering the Estuary
(Reprinted from Lower Columbia Fish Recovery Board 2004.)

Affected salmonids: It is likely that stream-type juvenile salmonids are most affected by short-term exposure to waterborne contaminants such as organophosphate pesticides and dissolved metals (Fresh et al. 2005). Ocean-type juveniles are affected by short-term exposure, too, but they also experience mortality from bioaccumulative toxicants such as DDT and PCBs that are absorbed during longer estuarine residence times (Fresh et al. 2005).

Limiting Factor: Bioaccumulation Toxicity. Potentially toxic water-soluble contaminants, trace metals, and chlorinated compounds have been observed in the estuary (Fresh et al. 2005). DDT and PCBs have been detected at elevated levels in juvenile salmonids using the estuary. These substances concentrate in animals near the top of the food chain. In a recent study by Loge et al., cumulative delayed disease-induced mortalities were estimated at 3 percent and 18 percent for juvenile chinook residing in the Columbia River estuary for 30 to 120 days, respectively (Loge et al. 2005). Figure 3-4 shows mean concentrations of PCBs and DDTS found in juvenile chinook in several locations of the Columbia River estuary and other Northwest estuaries.

Limiting Factor: Short-Term Toxicity. A variety of organochlorines (including aldrin, dieldrin, trichlorobenzene, and PAHs) in the estuary are above state and federal guidance levels (Lower Columbia River Estuary Partnership 2004a). As mentioned above, sublethal concentrations of contaminants can affect the survival of aquatic species by increasing stress, predisposing organisms to disease, delaying development, and disrupting physiological processes (Lower Columbia River Estuary Partnership 2004a). Figure 3-5 shows mean concentrations of PAHs in juvenile fall chinook in various locations of the Columbia River estuary and other Northwest estuaries.

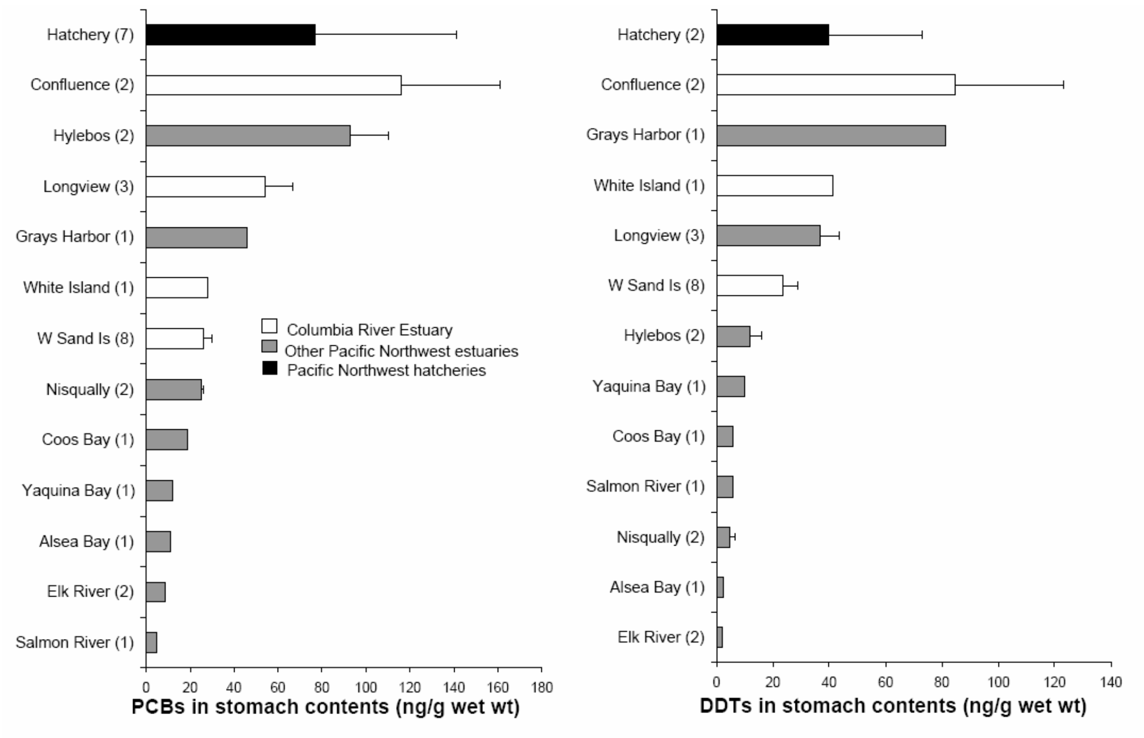

FIGURE 3-4
Mean Concentrations of PCBs and DDTs in Juvenile Chinook
(Reprinted from Fresh et al. 2005.)

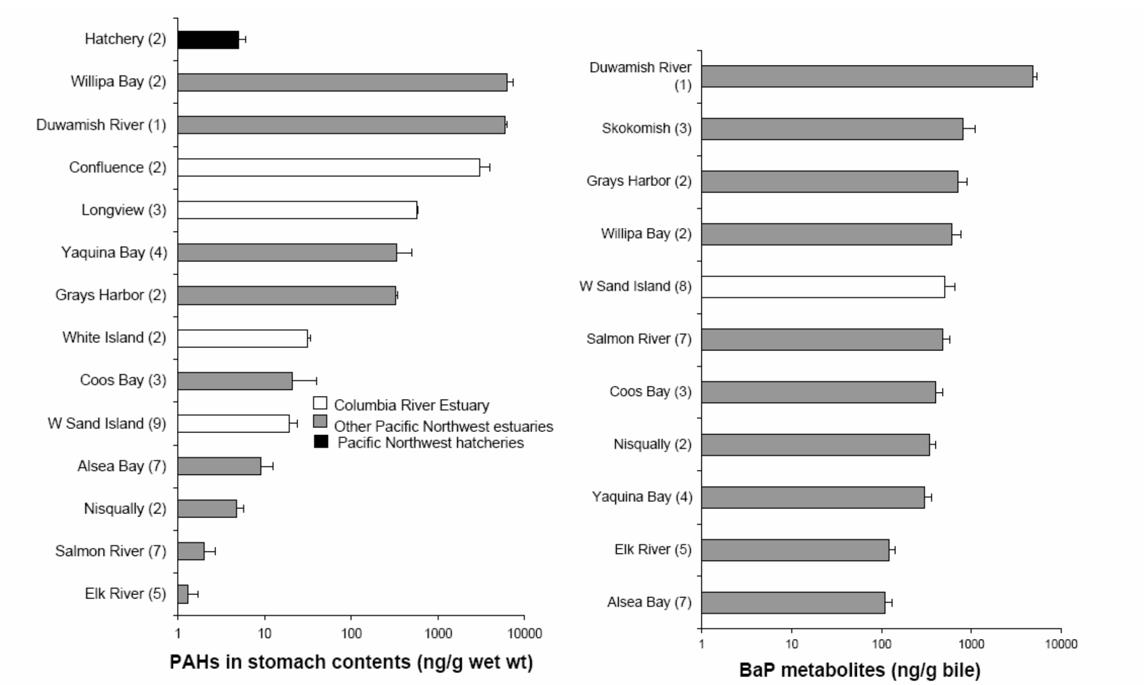

FIGURE 3-5
Mean Concentrations of Polycyclic Aromatic Hydrocarbons (PAHs) in Juvenile Chinook
(Reprinted from Fresh et al. 2005.)

Prioritization of Limiting Factors

All three of the primary literature sources used in this estuary recovery module identified flow, sediment, water quality, and food web alterations as limiting factors. In *Salmon at River's End* (Bottom et al. 2005), each of the limiting factor categories is analyzed in the context of habitat opportunity and capacity and how the limiting factor fits within the member/vagrant conceptual framework. In the Fresh technical memorandum, selected limiting factors are evaluated for their impacts on ocean- and stream-type ESUs. Limiting factors selected for analysis in Fresh et al. (2005) are tern predation, toxics, habitat, and flow. Finally, the *Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan* and its supplement (Lower Columbia River Estuary Partnership 2004a) evaluate limiting factors for their impacts to salmonids and the level of certainty that the factor is limiting.

This estuary recovery module uses a rating system to prioritize limiting factors by ocean- and stream-type salmon and steelhead. For each limiting factor, a score of 1 to 5 was assigned to both ocean- and stream-type salmonids. These scores were based on a synthesis of the three primary literature sources plus a host of others. An initial rating was performed by PC Trask & Associates with input from the Lower Columbia River Estuary Partnership, NOAA's Northwest Fisheries Science Center, NMFS' Portland office, and the Lower Columbia Fish Recovery Board. Additional reviews were used to refine scores. Although the three primary documents did not refer to stranding as a limiting factor, input from Washington Department of Fish and Wildlife staff was used to research the issue directly from other primary sources.

Table 3-1 shows the results of the limiting factor rating process. Each limiting factor received two scores—one for ocean-type salmonids and one for stream-type salmonids. One simplifying assumption in scoring is that both ocean- and stream-type salmonids express a diversity of life history strategies within ESUs and their constituent populations. Relative scores between ocean- and stream-type generally reflect the dominant life history stage by providing extra weight to the dominant life history strategy; however less dominant strategies are considered. For example, reduced off-channel habitat is primarily a limiting factor for ocean-type juveniles because the dominant life history strategy is subyearlings that use shallow-water habitats extensively to feed and rear. However, some ocean-type populations and subpopulations also express a yearling strategy as part of the overall genetic makeup of the population. As a result, both ocean- and stream-type salmonids received scores (albeit lower) for other less dominant life history strategies. The far right-hand column of the table is the total score, which adds ocean- and stream-type impact scores into a single composite score. The assumption that within healthy ESUs there is expression of less-dominant life history strategies is central to *Salmon at River's End* (Bottom et al. 2005) and the Fresh technical memorandum.

TABLE 3-1
Impact of Limiting Factors on Ocean- and Stream-Type Salmonids

Limiting Factor	Level of Impact		
	Ocean Type*	Stream Type*	Total Score
Habitat-Related Limiting Factors			
Reduced in-channel habitat opportunity			
Flow-related estuary habitat changes	5	3	8
Sediment-related estuary habitat changes	4	3	7
Reduced off-channel habitat			
Flow-related changes in access to off-channel habitat	5	3	8
Bankfull elevation changes	5	2	7
Reduced plume habitat opportunity			
Flow-related plume changes	3	5	8
Sediment/nutrient-related plume changes	2	3	5
Stranding	3	2	5
Food Web-Related Limiting Factors			
Food Source Changes			
Reduced macrodetritus inputs	5	3	8
Increased microdetritus inputs	4	2	6
Competition and Predation			
Native fish	3	2	5
Native birds	2	4	6
Native pinnipeds	2	2	4
Exotic fish	2	1	3
Introduced invertebrates	2	2	4
Exotic plants	2	2	4
Water Quality-Related Limiting Factors			
Temperature	4	3	7
Toxic contaminants			
Bioaccumulation toxicity	4	2	6
Short-term toxicity	4	3	7

*Significance of limiting factor to life history strategy:
1 = No likely effects.
2 = Minor effects on populations.
3 = Moderate effects on populations.
4 = Significant effects on populations.
5 = Major effects on populations.

Table 3-2 organizes limiting factors into groups based on total score. Top-priority limiting factors are those that have the greatest impact on both ocean- and stream-type ESUs, while lowest priority limiting factors have the least combined impact to ocean- and stream-type ESUs. An important assumption in the rating system is that all limiting factors had an effect on one or both ESU types.

TABLE 3-2
Limiting Factor Prioritization

Limiting Factor	Limiting Factor Score[a]	Limiting Factor Priority[b]
Flow-related estuary habitat changes	8	Top
Flow-related changes in access to off-channel habitat	8	
Reduced macrodetritus inputs	8	
Flow-related plume changes	8	
Increased microdetritus inputs	8	
Bankfull elevation changes	7	High
Sediment-related estuary habitat changes	7	
Short-term toxicity	7	
Temperature	7	
Native birds	6	Medium
Bioaccumulation toxicity	6	
Sediment/nutrient-related plume changes	5	Low
Stranding	5	
Native fish	5	
Exotic plants	4	Lowest
Introduced invertebrates	4	
Native pinnipeds	4	
Exotic fish	4	

[a]From Table 3-1.
[b]Limiting factors have been prioritized in groups, rather than individually, to avoid a false sense of precision in this qualitative analysis.

Summary

The identification of limiting factors in the Columbia River estuary is well supported in a variety of literature sources. Although sources take different approaches to lumping limiting factors together or splitting them apart for the purposes of evaluation, all of the documents generally agree that channel confinement and alterations to flows and sediment have significantly degraded the estuary ecosystem in far-reaching ways. Water quality and food web limiting factors also are well documented.

The interconnectedness of these limiting factors suggests the use of ecosystem-based analysis to understand more exactly their effects on salmonids; however, at this point modeling efforts cannot fully explain the complex relationships among limiting factors.

The next chapter examines human actions and natural events that cause or contribute to the limiting factors described in Chapter 3.

CHAPTER 4
Threats to Salmonids

Chapter 4 identifies and prioritizes threats to ESUs in the Columbia River basin. Threats are the human actions or natural events, such volcanic eruptions or floodplain development, that cause or contribute to limiting factors (Gaar 2005). Threats may be caused by past, present, or future actions or events.

The threats presented in this chapter were identified and prioritized using the same process and sources used to identify and prioritize limiting factors—that is, a thorough review and synthesis of pertinent literature (particularly Bottom et al. 2005, Fresh et al. 2005, and Lower Columbia River Estuary Partnership 2004a), supplemented by input by area experts. Both limiting factors and threats are well documented in these three key source documents, as well as in a number of other primary sources. In most cases limiting factors and threats are addressed together in the literature, and it required substantial effort to separate them for the purposes of this estuary recovery plan module.

The one threat presented in this chapter that was not mentioned in the main source documents is ship wakes, which can cause stranding of juvenile salmonids. Although the topic of stranding was first raised in a 1977 report (Bauersfeld 1977), the extent of stranding is unclear and the issue has remained quietly controversial and unresolved. An upcoming report by the University of Washington related to the navigational channel deepening project may shed additional light on the subject of stranding. The topic is addressed in this recovery plan module at the request of the Washington Department of Fish & Wildlife because ship wakes are estimated to cause high levels of mortality to ocean-type juveniles (primarily fry).

This chapter organizes threats to salmonids into the following groupings: flow, sediment, structures such as dikes and jetties, ship wakes, food web (including species relationships), and water quality in the estuary. The presentation of threats as discrete activities or phenomena is an oversimplification of complex physical and biological relationships that affect salmon survival. The threats related to flow, sediment transport, and food webs are particularly difficult to tease apart and discuss discretely. Thus the reader should bear in mind that describing threats individually probably does not fully capture the dynamic interplay of forces that are currently putting salmonids in the estuary at risk. The complexity of these forces is illustrated in Figure 4-1, which is a representation of a conceptual model of the Columbia River estuary developed by the U.S. Army Corps of Engineers. The model provides in-depth detail on the relationships between limiting factors and threats and is available at the following Web site: www.nwp.usace.army.mil/Pm/LCR/docs/CREConceptmodel/START.htm.

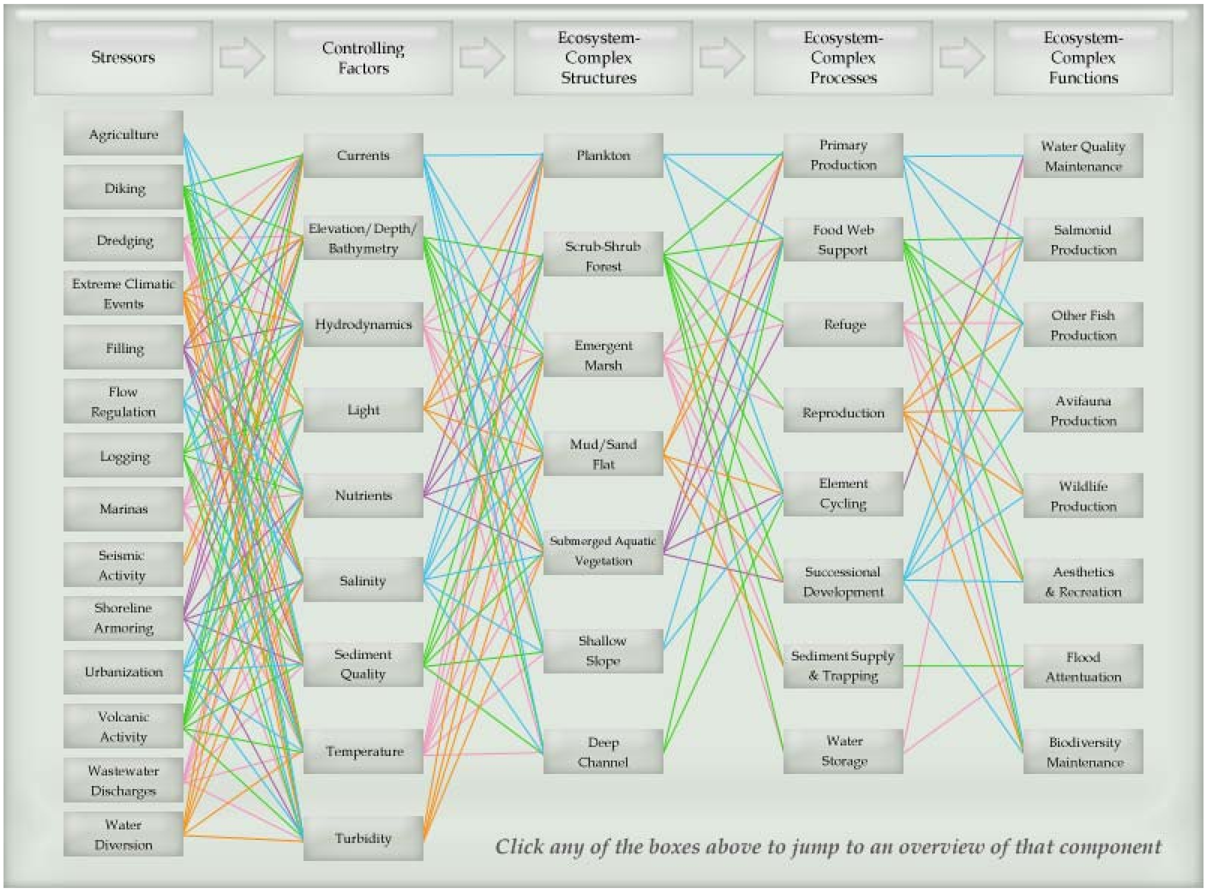

FIGURE 4-1
U.S. Army Corps of Engineers Conceptual Model of the Columbia River Estuary
(Full model available at www.nwp.usace.army.mil/Pm/LCR/docs/CREConceptmodel/START.htm.)

Most of the human threats described in this chapter are the result of the cumulative impacts of people living in the Northwest. From an ecological perspective these impacts have taken place relatively quickly. Consider that in 1770, when American Robert Gray first crossed the Columbia River bar, about 100,000 Native Americans lived in the Columbia River basin (Oregon State University 1998). Today the population of the interior Columbia Basin is approximately 5 million (National Research Council 2004). In the early years of Euro-American settlement, the area's abundant natural resources supported farming, mining, logging, fishing, and other activities that modified the landscape into productive uses for people. Later, the availability of cheap hydroelectric power helped fuel expanded agriculture, manufacturing, and development and the rise of urban centers such as Portland. The impacts of these activities on salmonids in the estuary have been substantial.

Flow-Related Threats

Over the last 4,000 years, salmon thrived in the Columbia River by adapting to habitats created by characteristics of the land and water flow (Fresh et al. 2005). Key attributes of flow include magnitude and timing, both of which have changed significantly in the Columbia River over the last two centuries. Today the mean flow to the estuary is about 16 percent less than it was in the latter part of the nineteenth century (Jay and Kukulka 2002), and spring freshet peak flows have declined about 44 percent in that same time period (Jay and Kukulka 2002). In addition, the timing of peak flows occurs about 14 to 30 days earlier than it did historically (Jay and Kukulka 2002). Reductions in the spring freshet flows are shown in Figure 4-2, which presents the annual Columbia River flow cycle measured at the Beaver Army Terminal near Quincy, Oregon, for the periods 1878 to 1903 and 1970 to 1999. The flows for 1878 to 1903 are reconstructed averaged flows.

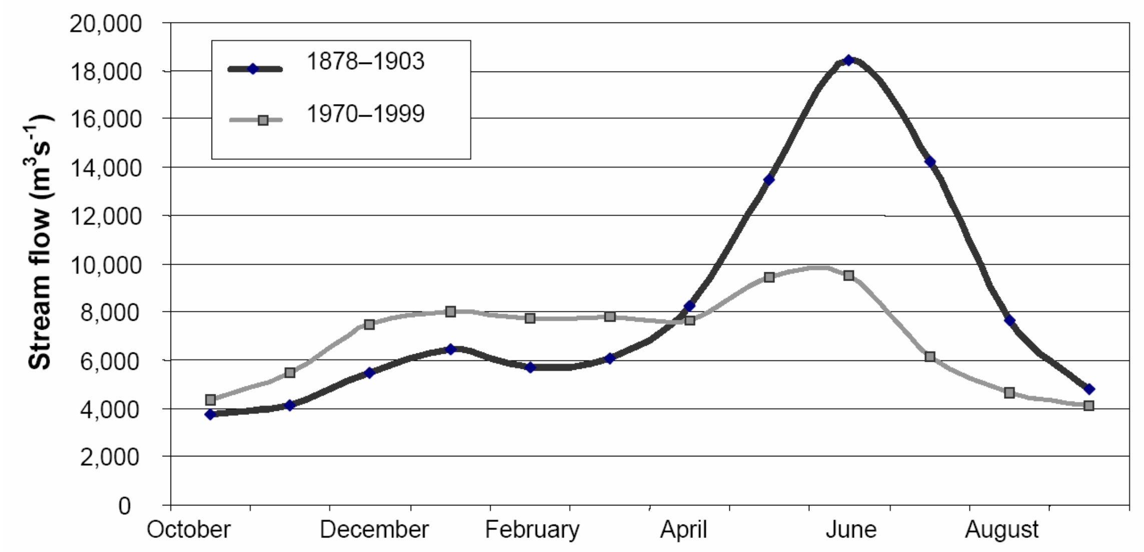

FIGURE 4-2
Changes in the Annual Columbia River Flow
(Reprinted from Bottom et al. 2005.)

Flow alterations, in connection with other factors, can increase or decrease salmonids' ability to access habitats and the capacity of habitats to sustain salmonids (Bottom et al. 2005). In the case of the Columbia River, alterations in the timing, magnitude, and duration of flows are responsible for dramatic changes in habitat opportunity and capacity in the estuary. Climate fluctuations, the withdrawal of water, and regulation of river flow have altered the amount and timing of instream flows entering the estuary and plume.

Affected salmonids: Alterations in the magnitude and timing of Columbia River flows affect both ocean- and stream-type juvenile salmonids. Ocean-type juveniles spend more time in the estuary, where they rely on shallow vegetated swamp and marsh habitats (Lower Columbia River Estuary Partnership 2004a). Chum salmon (ocean-type) also spawn in the mainstem and are affected by low flows during the spawning and egg incubation life stages—in extreme cases, redds may be dewatered. Ocean-type salmonids also rely on seasonal overbank flows to access habitats and preferred food sources.

Stream-type juveniles do not spend much time in the estuary, but recent research indicates that they may use the Columbia River plume habitat as they adjust to saltwater conditions (Fresh et al. 2005). Columbia River flows have a direct effect on the plume's surface area, volume, frontal features, and extent offshore (Fresh et al. 2005). Flow alterations also affect sediment transport processes.

Threat: Climate Cycles and Global Warming

Natural variations in Columbia River flow as a result of long- and short-term climate fluctuations have occurred throughout history. The Pacific Decadel Oscillation (PDO) alternates between cold and warm phases approximately every 30 years (Fresh et al. 2005). The cold, rainy phase is typical of the Northwest and increases flows, while the warm phase is drier and decreases flows (Fresh et al. 2005). The El Niño/Southern Oscillation (ENSO) is a shorter, 3- to 7-year phenomenon that similarly has cold and warm phases that may magnify or reduce the effects of the PDO. Over the last century, global warming has increased worldwide precipitation by about 1 percent and increased the frequency of extreme rainfall events in much of the United States (U.S. Environmental Protection Agency 2005).

Climatic fluctuations have a significant effect on the amount and timing of water flowing to the estuary (Fresh et al. 2005). Over the last 100 years, climatic changes have reduced Columbia River flows by 9 percent (Jay and Kulkulka 2002). In a recent memorandum, NOAA's Northwest Fisheries Science Center has observed changes in PDO and ENSO indicators that suggest that changes in ecosystem structure can be expected that are unfavorable for salmon and steelhead (Varanasi 2005). These changes are anticipated in late 2005 and may continue over the next several years.

Scientists believe that the release of high levels of carbon dioxide as a result of human activities is responsible for global warming. The source of these releases includes the use of fossil fuels to run cars, heat homes, and power factories. Over the past century, global warming has caused sea levels to rise about 4 to 5 inches (U.S. Environmental Protection Agency 2005). Worldwide precipitation has increased about 1 percent over land over the last 100 years, and the frequency of extreme rainfall events has increased over much of the United States (U.S. Environmental Protection Agency 2005). While global warming is a growing concern, this estuary recovery plan module does not factor it into climate's contribution to flow-related effects in the estuary. However, global warming should receive increasing attention for its potential to affect fish management in the Columbia River basin as a whole.

Limiting factors this threat contributes to: Flow-related estuary habitat and plume changes, flow-related changes in access to off-channel habitat, and reduced macrodetritus inputs.

Threat: Water Withdrawal

Reduction in the amount of instream flow in a river system is an important measure of alterations to the system (Fresh et al. 2005). Water withdrawals affect both the magnitude and timing of flows entering the estuary and plume.

Historically, flow conditions in the estuary were determined by seasonal climate effects (such as precipitation) and hydrology. Since the early 1900s and to a larger degree since the 1960s, irrigation practices have reduced flows in the Columbia River. Water withdrawals as a result of agricultural irrigation and other water uses are estimated to have reduced flows of the Columbia River by 7 percent since the latter part of the nineteenth century (Jay and Kukulka 2002).

Other human activities that reduce flows are the result of upstream use of surface water and groundwater for commercial, industrial, municipal, domestic, and other purposes (National Research Council 2004).

Irrigation withdrawals of surface water account for approximately 96 percent of total water used, while municipal and other uses account for only 4 percent (National Research Council 2004). On the other hand, about 75 percent of all groundwater withdrawals support irrigation and the remaining 25 percent are used for other purposes (National Research Council 2004).

Limiting factors this threat contributes to: Flow-related estuary habitat and plume changes, flow-related changes in access to off-channel habitat, and reduced macrodetritus inputs.

Threat: Flow Regulation

The timing and magnitude of spring freshets have been drastically altered by management of the Columbia River hydrosystem (Fresh et al. 2005). Jay and Kukulka (2002) estimate that 26 percent of the overall reduction of freshet season flow since the late nineteenth century is attributable to flow regulation. Together with irrigation, flow regulation has increased fall and winter flows (winter flows have increased because of pre-release before the freshet season), and much of the seasonal timing of flows in the estuary can be attributed to flood control and hydroelectric operations.

Flow regulation is a function of the hydrosystem in the United States and Canada. The first hydroelectric facility in the lower Columbia Basin—the T.W. Sullivan Dam in Oregon City—was constructed in 1888. Since then, more than 450 dams have been built in the Columbia River basin (Columbia Basin Trust). These dams supply British Columbia with 50 percent of its electricity, while the American Northwest relies on hydropower for about two-thirds of its electricity (Columbia Basin Trust). Columbia River dams also provide flood control, enhance irrigation, and improve navigation.

The total active storage of water in the Columbia River Basin is 42 million acre-feet (Northwest Power and Conservation Council 2001), with dams in Canada accounting for about half of the total storage (Northwest Power and Conservation Council 2001). Major Canadian dams include the Duncan, Arrow, and Mica dams. Major U.S. hydroelectric facilities with significant storage include the Grand Coulee, Dworshak, Hungry Horse, and Libby dams.

Several recent changes in hydrosystem operations have been implemented to benefit salmonids throughout the basin. These include increasing flows to benefit spring juvenile salmonid migration in the mainstem Snake and Columbia rivers. This action helps flows in real time instead of filling reservoirs. Also, summer flows have been augmented to assist Snake River fall chinook migration. Finally, a minimum flow has been administratively set from November through April to reduce the potential for dewatering of chum redds, primarily in Reach G in the estuary.

High dissolved gas levels associated with dam operations have resulted in significant salmon mortality, especially before the problem was identified and measures taken to reduce its incidence (Ebel 1969 as cited in Lower Columbia Fish Recovery Board 2004). Monitoring shows that salmonid mortality continues to be associated with spill events.

Limiting factors this threat contributes to: Flow-related estuary habitat and plume changes, flow-related changes in access to off-channel habitat, and reduced macrodetritus inputs.

Sediment-Related Threats

Changes to seasonal flows, dredging, and the entrapment of sediment in reservoirs have altered those habitat-forming processes in the Columbia River estuary that relate to sediment.

As described in Chapter 3, the transport of sediment is fundamental to habitat-forming processes in the estuary. Sediment also provides important nutrients that support food production in the estuary and plume. And suspended sediments contribute to turbidity, which is an important to salmonids because of the protection it provides from predators. Although the effects of impaired sediment processes on salmonids in the estuary are not fully understood, the magnitude of change and the key role that sediments play in habitat- and food-related processes are significant.

Entrapment of sediment in reservoirs, reduced downstream transport of sediment, and dredging are the primary sediment-related threats to salmonids in the estuary. Ocean-type juvenile salmonids are affected by sediment-related changes in habitat in the estuary. Stream-type juveniles are affected by reduced turbidity (which can increase predation) in deeper waters in the estuary and plume.

Threat: Entrapment of Sediment in Reservoirs

Reduction in water velocity as a result of upstream reservoirs has altered the transport of organics associated with fine sediments such as silt and clay. Fine sediments entering the estuary originate in the upper watersheds of the Snake River (Lower Columbia River Estuary Partnership 2004a). Reduced velocities behind upstream reservoirs act as a sink to fine sediments and likely reduce amounts delivered to the estuary (Lower Columbia River Estuary Partnership 2004a). Currently, organic matter associated with fine sediments supplies the majority of estuarine secondary productivity in the food web (Simenstad et al. 1984 as cited in Lower Columbia River Estuary Partnership 2004a).

Limiting factors this threat contributes to: Flow-related plume changes and sediment/nutrient-related estuary habitat changes.

Threat: Impaired Sediment Transport

Historically, the force of spring freshets moved sand down the river and into the estuary, where it formed shallow-water habitats that are vital for salmonids, particularly ocean types. Today, alterations to spring freshet flows have reduced sand discharge in the Columbia River estuary to 70 percent of nineteenth-century levels (Jay and Kukulka 2002). It is likely that the magnitude of change in sand transport affects habitat-forming processes and reduces turbidity, which results in increased predation in the estuary and plume environments.

Limiting factors this threat contributes to: Flow-related plume changes and sediment/nutrient-related estuary habitat changes.

Threat: Dredging

Dredging and the disposal of sand and gravel have been a major cause of estuarine habitat loss over the last century (Lower Columbia River Estuary Partnership 2004a). Currently, three times more sand is dredged from the estuary than is replenished by upstream sources (Lower Columbia River Estuary Partnership 2004a). In addition to causing habitat loss, dredging may have impaired sediment circulation systems in near-shore ocean areas.

Additional losses of vegetated wetlands in the Columbia River estuary are attributable to filling activities, with deposition of dredged materials accounting for most of the filling activities in the estuary (Fresh et al. 2005). Most dredged materials result from maintenance of the shipping channel. Dredged materials are disposed of in-water, along shorelines, or on upland sites. Annual maintenance dredging since 1976 has averaged 3.5 million cubic yards per year (Lower Columbia River Estuary Partnership 2004a). Dredge fill activities have significantly reduced the availability of wetlands to the river.

Limiting factors this threat contributes to: Sediment/nutrient-related estuary habitat and plume changes and native birds.

Structural Threats

The development of instream and over-water structures has altered circulation patterns, sediment deposition, sediment erosion, and the formation of habitats in the estuary. Examples of instream and over-water structures include jetties, pile dikes, tide gates, docks, breakwaters, bulkheads, revetments, seawalls, groins, and ramps (Williams and Thom 2001). Structural threats create favorable conditions for predators such as northern pikeminnow and walleye, and they can reduce circulation in areas outside of the channel. Structures are found in all reaches of the estuary.

Affected salmonids: Structural threats primarily affect ocean-type juvenile salmonids because of their longer residency time in the estuary and their wider use of off-channel habitats.

Threat: Jetties and Navigational Structures

Construction of the North and South jetties has altered sediment accretion and erosion processes near the mouth of the Columbia River. Sediment accretion in the marine littoral areas adjacent to the mouth has decreased the inflow of marine sediments into the estuary (Lower Columbia River Estuary Partnership 2004a), while the extensive use of other jetties and dikes to maintain the shipping channel has affected natural flow patterns. Development of the navigation channel has reduced flow to side channels and peripheral bays (Lower Columbia River Estuary Partnership 2004a). Docks, piers, and other structures have altered habitats and created favorable conditions for predators. In addition, saltwater intrusion patterns have been altered and nutrient cycles have been interrupted.

Limiting factors this threat contributes to: Sediment/nutrient-related estuary habitat and plume changes and exotic fish.

Threat: Dikes and Filling

Dikes and filling activities have significantly altered the size and function of the Columbia River estuary. Since the early 1900s, dikes have been built to allow agricultural and residential uses (Fresh et al. 2005). Dikes are thought to have caused more habitat conversion in the estuary than any other human or natural factor (Thomas 1983, as reported in Lower Columbia River Estuary Partnership 2004a). The effects of diking on estuarine habitats are directly proportional to elevation, with the greatest impacts on the highest elevation estuarine habitats: forested wetlands, followed by tidal swamps and tidal wetlands. Diking-related impacts to these habitats have reduced their availability to juvenile salmon and steelhead (Thomas 1983, as reported in Lower Columbia River Estuary Partnership 2004a). Figure 4-3 shows the various zones found in typical estuaries. The emergent vegetation, diked marsh, shrub wetlands, and forested wetlands are the zones most affected by dike and filling practices (reprinted from Thom 2001).

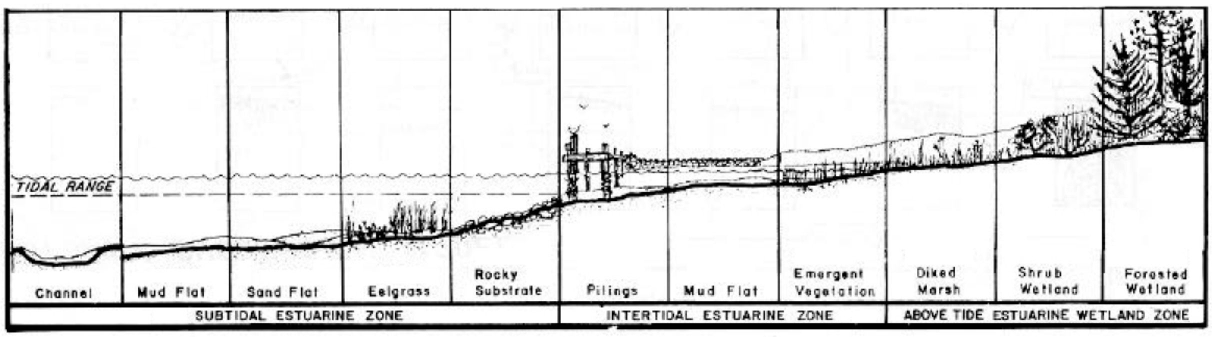

FIGURE 4-3
Subtidal, Intertidal, and Above-Tidal Estuarine Wetland Zones

Before development of the Columbia River hydrosystem and diking and filling, the estuary was dominated by macrodetrital inputs that originated from vegetated wetlands within the estuary. As a result of diking and filling practices and flow alterations (such as changes in the number and timing of spring freshets), emergent plant production in the estuary has decreased by 82 percent and macroalgae production has decreased by 15 percent (Lower Columbia River Estuary Partnership 2004a). The availability of insect prey for ocean-type salmonids has been reduced as vegetation has been removed via diking and filling activities and associated dike vegetation maintenance.

Limiting factors this threat contributes to: Reduced macrodetritus inputs, sediment/nutrient-related estuary habitat and plume changes, bankfull elevation increases, and exotic plants.

Threat: Over-Water Structures

Over-water structures refer to docks, transient moorage, log rafts, and other structures. These structures block sunlight, reduce flow, and trap sediments downstream of pilings. Over-water structures create microhabitats that may enhance predator habitats, alter circulation patterns, and reduce edge habitats for ocean-type salmonids. Although the actual square footage of over-water structures in the Columbia River estuary has never been inventoried, the structures themselves number in the thousands. Some research has occurred on the effects of breakwaters and over-water structures in the context of marinas. Salmon fry tend to concentrate in higher densities around these structures, thus increasing the risk of predation (Williams and Thom 2001).

Limiting factors this threat contributes to: Sediment/nutrient-related estuary habitat changes, and exotic fish.

Threat: Ship Wakes

Ships traveling through the Columbia River estuary produce waves and an uprush which, under certain circumstances, causes juvenile salmonids and other fish to become stranded on shore (Bauersfeld 1977). Although Bauersfeld concluded that ship wake stranding was a significant cause of mortality in ocean-type chinook salmon and other species, other studies have not confirmed this. Studies by the University of Washington and the Portland District of the Army Corps of Engineers may provide more conclusive information about this threat.

Limiting factors this threat contributes to: Stranding.

Food Web-Related Threats

As described in Chapter 3, changes in the estuarine food web can ripple through the ecosystem, altering feeding patterns, predator/prey relationships, and competition within and among species. The introduction of exotic species such as shad may have accelerated the pace of ecological change in the estuary by permanently altering food webs. Food webs also have been altered by sediment transport, in that microdetrital food particles adhere to sediment suspended in the water column, making different food sources available to different species than was the case historically.

Affected salmonids: Both stream- and ocean-type salmonids are affected by energy-related threats—stream types primarily through increased predation in deep-water habitats and ocean types primarily through food web changes in the estuary. Ocean-type juveniles also are affected by reduced availability of insect prey as a result of the construction and maintenance of dikes.

Threat: Reservoir Phytoplankton Production

A reduction in macrodetrital inputs has shifted the plant primary production in the estuary to phytoplankton produced in and imported from upstream reservoirs (Lower Columbia River Estuary Partnership 2004a). Imported phytoplankton support a pelagic food web that is less accessible to ocean-type salmonids occupying shallow edge habitats (Lower Columbia River Estuary Partnership 2004a). The shift in primary plant production from a macrodetrital base to a microdetrital base has provided different food sources than historically existed, in different places within the estuary, that then favor different species.

Limiting factors this threat contributes to: Increased microdetritus inputs.

Threat: Altered Predator/Prey Relationships

Although predation has always occurred in the estuary ecosystem, the cumulative effect of altered flows, changes in sediment transport processes and food sources, introduced species, hatcheries, upstream habitat impacts, hydroelectric impacts, and contaminants have recast estuary and plume environments such that predator/prey relationships have changed significantly. As a result, significant numbers of salmon are lost to fish, avian, and marine mammal predators during migration and residency in the estuary (Lower Columbia River Estuary Partnership 2004a). Fish predators include northern pikeminnow, walleye, smallmouth bass, and catfish; avian predators include Caspian terns, double-breasted cormorants, and gull species; and marine mammal predators include Steller and California sea lions and harbor seals.

Degraded conditions (loss of habitat and reduced food web productivity) in the Columbia River estuary and the timing of large hatchery releases have increased the likelihood that mortality from competition may occur under some circumstances (Lower Columbia River Estuary Partnership 2004a). Mortality from inter-species competition has been documented in the Skagit River estuary (Beamer et al. 2005), and there is speculation that it may be a factor in the Columbia River as well (Lower Columbia River Estuary Partnership 2004a). If inter-species competition is occurring, it is likely to have the greatest impact on ocean-type salmonids because of their longer residence time in the estuary (Lower Columbia River Estuary Partnership 2004a). If density dependence is affecting stream-type juveniles, it likely happens in the plume.

As the result of human alterations of the estuary environment, native species such as Caspian terns and double-breasted cormorants have significantly increased in number, with measurable impacts on stream-type salmonids (Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers 2004). These increases in population are attributed to the deposition of dredge materials in the estuary that represent high-quality habitat for the birds (Bottom et al. 2005). Similarly, the new microdetritus-based food web in the estuary has benefited zooplanktivores, including American shad (an introduced species) (Lower Columbia River Estuary Partnership 2004a). Although shad do not appear to be in direct competition with salmonids, their biomass alone—more than 4 million returning adults a year—represents a threat to trophic relationships in the Columbia River. Other exotic fish species such as introduced walleye and catfish also have been able to capitalize on degraded conditions in the upper reaches of the estuary and alter food web dynamics through predation and competition for food resources. Walleye, for example, prey directly on juvenile salmonids.

Non-native plant species have altered habitat and food webs in the Columbia River estuary. The rate of intentional and unintentional introductions has been increasing over the past 100 years, mostly as a result of horticultural practices and the increase in travel and commerce in the Columbia River. Four of those species—purple loosestrife, Eurasian water milfoil, parrot feather, and Brazilian elodea—are of particular concern. Each of these species, in its own way, alters habitat and food webs in the estuary. Purple loosestrife, for example, adapts easily to environmental changes and expands its ranges quickly. The primary ecological effect of purple loosestrife is that it disrupts wetland ecosystems by displacing native plants. Eventually, animals that rely on native flora for food, nesting, or cover also are displaced (Lower Columbia River Estuary Partnership 2004a).

Limiting factors this threat contributes to: Native birds, native fish, native pinnipeds, introduced invertebrates, exotic fish, and exotic plants.

Threat: Ship Ballast Practices

Ship ballast practices have been responsible for the introduction of at least 21 exotic species in the Columbia River estuary (Sytsma et al. 2004). When ships release ballast water, non-indigenous species can enter receiving waters. Most of the non-indigenous species in the estuary have originated from Asia (Sytsma et al. 2004). Populations of non-native copepods have established themselves in Reaches A and B (Youngs Bay, Cathlamet Bay, and Grays Bay), and the New Zealand mudsnail has colonized other estuary reaches. The Asian bivale *Corbicula fluminea* has expanded its range in the estuary, with densities of 10,000 m^2 being recorded in Cathlamet Bay (Lower Columbia River Estuary Partnership 2004a). These and other non-indigenous invaders disrupt food webs and out-compete juvenile salmonids' native food sources.

Limiting factors this threat contributes to: Introduced invertebrates.

Water Quality-Related Threats

Temperature increases, the release of toxic contaminants, nutrient loading, and reduced dissolved oxygen have altered the quality of salmonid habitats in the Columbia River estuary. Currently the estuary receives contaminants from more than 100 point sources and numerous non-point sources, such as surface and stormwater runoff from urban and agricultural areas (Fuhrer et al. 1996 as referenced in Fresh et al. 2005). Agricultural, urban, industrial, and timber harvesting practices also affect water quality in the estuary, as does reservoir heating.

Threat: Agricultural Practices

The health of the aquatic ecosystem is substantially affected by agricultural practices and wastewater discharge (National Research Council 2004). Specific threats include increased nutrients (nitrogen and phosphorus), sediment, and organic and trace metals (National Research Council 2004). Agricultural practices in the estuary and throughout the Columbia River basin contribute water-soluble contaminants and other potentially toxic contaminants. The U.S. Geological Survey's National Stream Quality Accounting Network (NASQAN) program reports that a wide range of commonly used pesticides have been detected at sampling sites near Bonneville Dam and at the confluence of the Willamette and Columbia rivers (Fresh et al. 2005). Detected water-soluble contaminants include simazine, atrazine, chlorpyrifos, metolachlor, diazinon, and carbaryl. Arsenic and trace metals such as iron and manganese also have been detected. Although trace metals occur naturally, they also are introduced through human activities, such as the use of lead arsenate as an insecticide for apples (Fresh et al. 2005). Water-soluble contaminants, trace metals, and chlorinated compounds have been detected in the estuary (Fresh et al. 2005), and DDT, PCBs, dioxins, and metals have been detected at elevated levels in tissue from fish in the estuary (Lower Columbia River Estuary Partnership 2004a).

Limiting factors this threat contributes to: Sediment /nutrient-related plume changes, short-term toxicity, and bioaccumulation toxicity.

Threat: Urban and Industrial Practices

The Columbia River downstream of Bonneville Dam is the most urbanized stretch in the entire basin. The largest sources of effluent in this area are the Portland and Vancouver sewage treatment plants (Fresh et al. 2005). Contaminants also are transported downstream to the estuary from areas above Bonneville Dam. An intensive study of sediments in Portland Harbor (the stretch of the Willamette River from Sauvie Island to Swan Island) has uncovered pesticides, PCBs, and other toxic chemicals. In general, studies have shown that PCB and PAH concentrations in salmon and their prey in the estuary are comparable to those in organisms in other moderately to highly urbanized areas (Fresh et al. 2005). Industrial contaminants such as PAHs have been detected in sediments from the lower Willamette River in Portland at levels that exceed state or federal sediment quality guidelines. The U.S. Environmental Protection Agency recently identified PCB and DDT hot spots within the estuary, including near Longview, West Sand Island, the Astoria Bridge, and Vancouver (Fresh et al. 2005).

Limiting factors this threat contributes to: Temperature, short-term toxicity, and bioaccumulation toxicity.

Threat: Timber Riparian Practices

Timber harvesting activities in tributaries throughout the Columbia River basin have contributed to estuary temperature increases by changing hydrology and removing riparian habitats (National Research Council 2004). Timber harvest is a widespread land use in the Columbia River basin and occurs most heavily on private timberlands. If forest roads are improperly located, constructed, or maintained, they can degrade stream flow and sediment supply processes. Other potential threats include harvest on unstable slopes, clear cutting in rain-on-snow zones, unsurfaced roads, and the use of forest fertilizers, herbicides, and pesticides (Lower Columbia Fish Recovery Board 2004).

Limiting factors this threat contributes to: Temperature.

Threat: Reservoir Heating

More than 450 dams have been built in the Columbia River basin (Columbia Basin Trust). The associated impoundment of water in upstream reservoirs increases the surface area of the Columbia River, allowing more solar heating of river water than occurs in free-flowing river stretches. This solar heating, combined with the reduced flows from upstream impoundments, has contributed to increased water temperatures in the Columbia River. Measurements at Bonneville Dam indicate that periods of increased temperatures are lasting longer than they did historically (National Research Council 2004). Currently, average and maximum values of Columbia River water temperatures are well above 20° C, which approaches the upper limits of thermal tolerance for cold-water fishes such as salmon (National Research Council 2004).

Limiting factors this threat contributes to: Temperature.

Prioritization of Threats

The threats identified above are well supported in a wide variety of literature sources. In many cases, primary literature sources are cross-referenced in the literature and restated and synthesized through comprehensive documents like the *Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan* (Lower Columbia River Estuary Partnership 2004a).

The prioritization of threats, though, is not nearly as well supported, partly because of the limited understanding of how threats contribute to limiting factors and to what degree salmon and steelhead are affected by a given limiting factor. While it is attractive to assume that additional study will fully answer these questions, the biological response to environmental conditions will always be difficult to model because of the tremendous complexities of the physical, biological, and ecological interplay that occurs in the environment. On the other hand, new interest in the estuary and its role in the recovery of listed species in the Columbia River has generated better understanding, and it is likely that uncertainty surrounding threats and limiting factors will continue to lessen.

This estuary recovery module establishes priorities for threats by linking them to pertinent limiting factors and estimating their relative contribution to those limiting factors. Literature sources were very useful in making connections between threats and limiting factors. In nearly all cases, authors discussed cause-and-effect relationships in typically qualitative language. In some cases quantitative relationships were established, as in the relationship between flow regulation and sediment transport. Only a handful of sources estimated priorities for either limiting factors or threats.

Table 4-1 links the limiting factors and threats identified in this estuary recovery plan module and estimates the relative contribution of each threat to one or more limiting factors. Although the information presented in the table is oversimplified, given the state of the science the table functions adequately as tool to help identify management actions in Chapter 5.

To the degree possible, Table 4-1 demonstrates the relationship between threats and limiting factors by showing which threats are causing which limiting factors and estimating the contribution of each threat to the various limiting factors. The contribution scores in the table were first estimated by PC Trask & Associates by synthesizing information from many literature sources. Scores were then refined through review and input by NOAA's Northwest Fisheries Science Center, NMFS staff, Lower Columbia River Estuary Partnership staff, and Lower Columbia Fish Recovery Board staff. Additional review and input will occur in 2006 to refine and improve the estimates prior to final publication.

Also in Table 4-1, the contribution of each threat to its associated limiting factor(s) is multiplied by the relative importance of that limiting factor to salmonids (the relative importance of limiting factors is taken from Table 3-2). This yields a threat index score, which expresses the relative priority of the threat in question.

Lastly in the prioritization process, Table 4-2 organizes threats in descending order and establishes priorities for groups of threats, using numerical break points to separate groups.

The state of the science is such that the differentiation of threat priorities in Table 4-2 should be viewed as reasonable guidance rather than hard, quantitative data. For example, it is difficult to dispute the importance of flow regulation compared to ship ballast practices. However, given uncertainties about ecosystems and how they function, some lower ranking threats may have tremendous impacts to the estuary in the long run. Continuing the example of ship ballast practices, it is possible that the effects of exotic invertebrates introduced to the estuary through ship ballast practices will significantly degrade the overall health of the estuary ecosystem over time.

TABLE 4-1
Linkages Between Limiting Factors and Threats to Ocean- and Stream-Type Salmonids

Limiting Factor	Threat	Limiting Factor Priority & Numerical Score[a]	Contribution of Threat to Limiting Factor, & Numerical Score[b]	Threat Index[c]
Flow-related estuary habitat changes	Climate cycles and global warming	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Flow regulation	Top (5)	Primary (3)	15
Flow-related changes in access to off-channel habitat	Climate cycles and global warming	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Flow regulation	Top (5)	Primary (3)	15
Flow-related plume changes	Climate cycles and global warming	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Flow regulation	Top (5)	Primary (3)	15
	Impaired sediment transport	Top (5)	Primary (3)	15
	Entrapment of sediment in reservoirs	Top (5)	Secondary (2)	10
Reduced macrodetritus inputs	Climate cycles and global warming	Top (5)	Secondary (2)	10
	Water withdrawal	Top (5)	Secondary (2)	10
	Flow regulation	Top (5)	Primary (3)	15
	Dikes and filling	Top (5)	Primary (3)	15
Increased microdetritus inputs	Reservoir phytoplankton production	Top (5)	Primary (3)	15
Sediment/nutrient-related estuary habitat changes	Impaired sediment transport	High (4)	Primary (3)	12
	Entrapment of sediment in reservoirs	High (4)	Primary (3)	15
	Dredging	High (4)	Tertiary (1)	4
	Jetties and navigational structures	High (4)	Secondary (2)	8
	Dikes and filling	High (4)	Primary (3)	12
	Over-water structures	High (4)	Tertiary (1)	4
Bankfull elevation changes	Dikes and filling	High (4)	Primary (3)	12
Temperature	Reservoir heating	High (4)	Primary (3)	12
	Urban and industrial practices	High (4)	Secondary (2)	8
	Timber riparian practices	High (4)	Primary (3)	12

Short-term toxicity	Agricultural practices	High (4)	Primary (3)	12
	Urban and industrial practices	High (4)	Primary (3)	12
Native birds	Dredging	Medium (3)	Primary (3)	9
	Altered predator/prey relationships	Medium (3)	Secondary (2)	6
Bioaccumulation toxicity	Agricultural practices	Medium (3)	Primary (3)	9
	Urban and industrial practices	Medium (3)	Primary (3)	9
Native fish	Altered predator/prey relationships	Low (2)	Primary (3)	6
Sediment/nutrient-related plume changes	Dredging	Low (2)	Primary (3)	6
	Jetties and navigational structures	Low (2)	Secondary (2)	4
	Dikes and filling	Low (2)	Secondary (2)	4
Stranding	Ship wakes	Low (2)	Primary (3)	6
Native pinnipeds	Altered predator/prey relationships	Lowest (1)	Primary (3)	3
Introduced invertebrates	Altered predator/prey relationships	Lowest (1)	Tertiary (1)	1
	Ship ballast practices	Lowest (1)	Primary (3)	3
Exotic fish	Over-water structures	Lowest (1)	Secondary (2)	2
	Jetties and navigational structures	Lowest (1)	Secondary (2)	2
	Altered predator/prey relationships	Lowest (1)	Secondary (2)	2
Exotic plants	Dikes and filling	Lowest (1)	Primary (3)	3
	Altered predator/prey relationships	Lowest (1)	Primary (3)	3

[a]From Table 3-2.

[b]Indicates how important the threat is in perpetuating the limiting factor.

3 = Threat is a primary cause of the limiting factor. Addressing this threat would significantly improve salmonid performance.

2 = Threat is a secondary cause of the limiting factor. Addressing this threat would improve performance.

1 = Threat is a tertiary cause of the limiting factor. Addressing this threat would benefit performance, but by itself would result in only minor improvement.

[c]Product of the numerical scores for the limiting factor priority and the threat's contribution to the limiting factor. A high threat index score means that the threat is a major contributor to one or more significant limiting factors. A low threat index score means the threat is a small contributor to a minor limiting factor

TABLE 4-2
Prioritization of Threats to Ocean- and Stream-Type Salmonids

Threat	Threat Index*	Threat Priority
Flow regulation	15	High
Dikes and filling	15	
Impaired sediment transport	15	
Reservoir phytoplankton production	15	
Entrapment of sediment in reservoirs	12	Medium-high
Urban and industrial practices	12	
Agricultural practices	12	
Reservoir heating	12	
Timber riparian practices	12	
Climate cycles and global warming	10	Medium
Water withdrawal	10	
Jetties and navigational structures	8	
Altered predator/prey relationships	6	Medium-low
Ship wakes	6	
Dredging	6	
Ship ballast practices	3	Low
Over-water structures	2	

* From Table 4-1. Indicates the significance of the associated limiting factor and the threat's contribution to that limiting factor. High numbers indicate threats that have a major contribution to high-priority limiting factors; lower numbers indicate threats that have a minor contribution to low-priority limiting factors. Numbers indicate the highest score per threat category and do not account for multiple limiting factor contributions.

Summary

The limiting factors that ocean- and stream-type ESUs encounter in the estuary are a result of upstream and estuary threats. Threats are well-documented in primary and secondary literature sources, although the complexity of interactions at the ecosystem-scale has caused treatment of threats to be inconsistent. New research efforts in the estuary and plume, as in other estuaries around the Northwest, are providing insights into salmonid ecology. For example, a recent University of Washington graduate student gathered data about prey and foraging activities of fall chinook salmon in the estuary and found midge insect prey to be a dominant food source. This raises new concerns about the threat of dikes and filling to ocean-type ESUs that rely on vegetated wetlands for insect prey. In addition, the identification of density-dependent mortality in the Skagit River delta has raised the question of whether density dependence-related mortality is also occurring in the Columbia River estuary. Continued research by NOAA's Northwest Fisheries Science Center and monitoring programs like the Lower Columbia River Estuary Partnership contaminant flux model should help reduce uncertainty over time.

The prioritization of threats in Table 4-2 is consistent with contemporary literature sources. Additional review and input from the science community in 2006 should help clarify the linkages among and significance of threats and limiting factors.

In Chapter 5, management actions are identified and prioritized that, if implemented, would help reduce threats that contribute to limiting factors. The identification and prioritization of management actions presents different challenges—this is where science, policy, and constraints intersect.

CHAPTER 5

Management Actions

This chapter identifies and prioritizes management actions that, if implemented, would reduce the impacts of threats to salmonids during their migration and residency in the Columbia River estuary and plume (see Chapter 4 for descriptions of threats). For each threat, management actions were identified using available literature and input from area experts. Actions were then evaluated for their feasibility, potential to improve salmonid survival, and relative cost, based on a review of the literature—especially the *Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan* (Lower Columbia River Estuary Partnership 2004a) and its supplement, Fresh et al. (2005), and the *FCRPS Biological Opinion Remand* (Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers 2004). Finally, the potential for improvement in survival was compared to the costs of each action, yielding three categories of management actions that represent priorities in this estuary recovery module.

Uncertainty exists at each of these steps. This is because many aspects of the salmonid life cycle are poorly understood. Much of this uncertainty stems from the sheer complexity of the many ecosystems that salmonids transition into and out of during their lives. Given the complexity of the subject matter, it is expected that this recovery plan module will be reviewed further in 2006 to refine ratings and management actions that would be expected to improve the survival of salmonids using the estuary and plume.

Identification of Management Actions

For the purposes of this recovery module, a management action is any action that has the potential to reduce the impact of human-caused or naturally occurring threats to salmonids while they migrate or rear in the estuary or plume. Table 5-1 lists threats to salmonids in the estuary and plume and corresponding management actions that would address those threats. As described above, the management actions have been gleaned from a review of contemporary literature, supplemented by direct input from area experts.

Most threats in Table 5-1 have several management actions associated with them. (The exception to this is climate cycles and global warming because the likelihood of management actions effecting change in this arena is low.) The table shows each management action correlating directly with a single threat. However, given the complexity of the riverine, estuarine, and marine ecosystems that salmon use during their lives, the actual relationships among threats and potential management actions are much more complicated than Table 5-1 suggests.

TABLE 5-1
Identification of Potential Management Actions and Their Correlation to Threats

Threat	Management Action
Flow regulation	Incorporate estuary flow considerations into the management of hydrosystem to increase spring freshet flows.
	Incorporate estuary flow considerations into management of the hydrosystem to adjust the timing and increase the magnitude and frequency of flows to better mimic historical conditions.
Dikes and filling	Protect remaining high-quality off-channel habitat from degradation through regulatory, fee simple, and less-than-fee acquisition.
	Restore off-channel habitat by breaching (or lowering) dikes and levees where possible.
	Remove tide gates where appropriate.
	Upgrade tide gates where (1) no other option exists, (2) structures can provide appropriate access for juveniles, and (3) ecosystem function would be improved over current conditions.
Impaired sediment transport	Increase spring flows to enhance the transport of sand and gravels through the estuary, plume, and ocean nearshore.
	Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.
Reservoir phytoplankton production	Increase macrodetrital inputs and other historical food sources in the estuary to compensate for reservoir phytoplankton production, which is a permanent ecosystem alteration.
Water withdrawal	Upgrade up-river irrigation structures using water conservation best management practices to reduce evaporation and conveyance losses to improve estuary instream flows.
	Implement water conservation best management practices for public and private water purveyors.
	Establish legal instream flows for the Columbia River and tributaries that would prevent further degradation of downstream ecosystems.
	Incorporate water availability analysis in land use planning activities to ensure efficient use of water.
Urban and industrial practices	Implement stormwater and runoff best management practices in cities and towns.
	Protect intact riparian areas and restore riparian areas that are degraded.
	Locate sources of industrial and commercial pollutants and take steps to reduce inputs.
	Monitor the estuary for contaminants and restore contaminated sites where appropriate.
Entrapment of sediment in reservoirs	Study and mitigate the effects of entrapment of sediment in reservoirs.

Agricultural practices	Implement pesticide and fertilizer best management practices to reduce estuary and upstream sources of toxic materials entering the estuary.
Reservoir heating	Manage the hydrosystem to reduce reservoir surface heating.
Timber riparian practices	Protect and restore timberland riparian areas for shade and future wood sources.
Climate cycles and global warming	[No actions identified.]
Jetties and navigational structures	Remove jetties and navigational structures that have low navigational value but high impact on estuary circulation and/or juvenile predation effects.
Altered predator/prey relationships	Manage smallmouth bass, walleye, and channel catfish to prevent increases in abundance.
	Reduce the impacts on salmonids by pinnipeds.
	Increase the effectiveness of aquatic noxious weed laws through education, monitoring, and enforcement.
	Reduce the abundance levels of Caspian terns nesting on islands created by disposal of dredged material.
	Reduce the abundance levels of shad entering the estuary.
Ship wakes	Reduce the effects of vessel wake stranding in the estuary.
Over-water structures	Reduce the square footage of over-water structures in the estuary.
Dredging	Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities in the estuary.
Ship ballast practices	Implement best management practices to prevent new introductions of invertebrates in the estuary.

Evaluation of Management Actions

Management actions can be evaluated from a variety of perspectives. In this qualitative analysis, 31 potential management actions were evaluated in terms of the priority of the threat they would address, their feasibility, their potential to improve salmonid survival, and their relative cost.

Threat Priority

Each potential management action was evaluated first in terms of the priority of the threat it would address. The threat priority reflects the degree to which a given threat perpetuates one or more limiting factors and the significance of those limiting factors, meaning the degree to which they limit salmonid performance. The priority of each threat is shown in Table 4-2, while Tables 3-2 and 4-1 show how the threat priorities were derived from limiting factors.

Feasibility

The feasibility of each management item estimates the likelihood that the action can be implemented. In general, information on the feasibility of management actions is not well supported in the literature. However, the *Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan* (Lower Columbia River Estuary Partnership 2004a) does include a "likelihood of success" rating for its proposed measures, and other literature sources often contained statements about feasibility when discussing threats and limiting factors.

Potential for Improvement in Survival

The potential for improvement in survival predicts the level of benefit that could reasonably be expected if the management action were to be implemented. Potential for improvement in survival is a function of each management action's threat priority and feasibility. Key assumptions built into the rationale for potential improvement in survival also were considered.

Relative Cost

Relative cost includes both direct and indirect costs associated with implementing a potential management action. For the purposes of this document, direct costs are those out-of-pocket costs that public or private interests would pay to implement a potential management action. For example, the direct costs of removing a barrier would be those associated with engineering, designing, and constructing the elements of the particular project. Indirect costs, on the other hand, represent the costs of foregone opportunities or costs to the overall local or regional economy. This chapter's discussion of the costs of management actions is not an in-depth economic analysis. Rather, it is intended to highlight the relative costs of different management actions, especially when considered with respect to the potential biological and physical benefits those management actions could provide.

Results

Table 5-2 shows the results of this evaluation. In Table 5-2, the threat priority is taken from Table 4-2. The feasibility of the management action is rated high, medium, or low according to how fully the action could be implemented within reasonable constraints (implemented, partially implemented, or little or no part of the action implemented, respectively). Likewise, the potential for improvement in survival is rated high, medium, or low given the threat priority and feasibility of the management action. A high rating assumes that the action would result in significant improvements in survival, a medium rating assumes that the action would result in moderate improvements, and a low rating assumes that the action would result in minor improvements.

TABLE 5-2
Evaluation of Potential Management Actions

Management Action: Incorporate estuary flow considerations into management of the hydrosystem to increase spring freshet flows.

Threat this action would address		**Flow regulation.** Spring freshet flows are important for habitat-forming processes and also improve access to off-channel habitats such as forested wetlands, vegetated wetlands, tidal swamps, and tidal marshes. In addition, access to these habitats increases insect feeding patterns displayed by subyearlings.
Threat priority[1]	High	This threat is linked to many limiting factors, including estuary habitat changes, off-channel habitat access, plume habitat changes, and reduced microdetritus inputs in the estuary. The high designation is suggested because this threat is a primary cause of several top-priority limiting factors.
Feasibility of action[2]	Low	Constraints on hydrosystem operations prevent the return to a natural hydrograph in the estuary. However, incremental increases in spring freshet flows are possible and would provide important additional habitat when use by juvenile fish is at its highest. Implementation of this action would be limited by international treaties, the need for flood control, and power management constraints.
Key assumption		Evaluation of this management action assumes that the timing and magnitude of spring freshets is more actively considered in the management of the hydrosystem and that incremental change would help improve available habitats and food inputs.
Potential for improvement in survival[3]	Low (high threat priority and low feasibility of action)	Because flow regulation is believed to be one of the most significant limiting factors in the estuary, it is likely that managing the hydrosystem to mimic the historical hydrograph would greatly improve salmonid survival rates. However, there are significant barriers to managing flows in the estuary to mimic the historical hydrograph. As a result, the potential for improvement in survival is estimated to be low. Ocean-type salmonids in the estuary would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported. Stream-type salmonids in plume habitats also could benefit.
Relative cost	Medium	Direct costs would primarily be associated with U.S. and Canadian programs responsible for establishing Columbia River flows. Cost would primarily be a function of technical and policy analysis within existing programs. The indirect costs of increasing spring freshet flows in the estuary have the potential to be extremely high; however, foregone electricity production, gas supersaturation issues, the need for flood control, and legal constraints place limits on the potential for increases in estuary flow. Given these limits, it is likely that the actual economic effects would be only moderate. Indirect costs would include, but not be limited to, higher prices for domestic, commercial, and industrial electricity and foregone opportunities to sell wholesale electricity to markets.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Incorporate estuary flow considerations into management of the hydrosystem to adjust the timing and increase the magnitude and frequency of flows to better mimic historical conditions.

Threat this action would address		**Flow regulation.** The magnitude, frequency, and timing of flows are an important determinant of habitat opportunity for salmonids in the estuary. Salmonids have adapted to historical flows and depend on them to complete their life cycles.
Threat priority[1]	High	This threat is linked to many limiting factors, including estuary habitat changes, off-channel habitat access, plume habitat changes, and reduced microdetritus inputs in the estuary. The high designation is suggested because this threat is a primary cause of several top-priority limiting factors.
Feasibility of action[2]	Low	Constraints on hydrosystem operations prevent the return to a natural hydrograph in the estuary. However, it may be possible to adjust hydrosystem operations incrementally to increase salmonid habitat opportunity in the estuary. Implementation of this action would be limited by international treaties, the need for flood control, fish management objectives, and power management.
Key assumption		Evaluation of this management action assumes that small to moderate changes in the magnitude, frequency, and timing of flows would improve habitat opportunity in the estuary.
Potential for improvement in survival[3]	Low (high threat priority and low feasibility of action)	Because flow regulation is believed to be one of the most significant limiting factors in the estuary, it is likely that managing the hydrosystem to mimic the historical hydrograph would greatly improve salmonid survival rates. However, there are significant barriers to managing flows in the estuary to mimic the historical hydrograph. As a result, the potential for improvement in survival is estimated to be low. Ocean-type salmonids in the estuary would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported, as would stream-type juveniles rearing in the plume.
Relative cost	Medium	Direct costs would primarily be associated with U.S. and Canadian programs responsible for establishing Columbia River flows. Cost would primarily be a function of technical and policy analysis within existing programs. The indirect costs of altering the magnitude and timing of flows in the estuary have the potential to be extremely high; however, foregone electricity production, gas supersaturation issues, the need for flood control, and legal constraints place limits on the potential for increases in estuary flow. Given these limits, it is likely that the actual economic effects would be only moderate. Indirect costs would include, but not be limited to, higher prices for domestic, commercial, and industrial electricity and foregone opportunities to sell wholesale electricity to markets.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Protect remaining high-quality off-channel habitat from degradation through regulatory, fee simple, and less-than-fee acquisition.

Threat this action would address		**Dikes and filling.** Human activities along both sides of the estuary have reduced floodplain inundation and access to historical wetlands and swamps. Protection of off-channel habitats would help maintain important wetland habitats and supply macrodetrital inputs and insect food sources.
Threat priority[1]	High	This threat is linked to many limiting factors, including reduced macrodetritus inputs, sediment/nutrient-related estuary habitat changes, bankfull elevation changes, sediment/nutrient-related plume changes, and exotic plants. The high designation is suggested because this threat is a primary cause of both top-priority and high-priority limiting factors.
Feasibility of action[2]	Medium	Protection of remaining high-quality off-channel habitats is challenging. Regulatory programs often do not effectively protect floodplains from conversion. Acquisition is expensive and depends on the willingness of landowners to sell. The feasibility of this action is considered to be medium because opportunities to protect high-quality habitats exist but are limited.
Key assumptions		Evaluation of this management action assumes that protection opportunities can be increased over the next decade through public awareness, education, regulation, and acquisition programs.
Potential for improvement in survival[3]	Medium (high threat priority and medium feasibility of action)	The combination of reduced spring freshet flows, the construction of dikes, and backfilling activities in the estuary has almost completely eliminated overbank flow events and historical access to wetland habitats. Protection of remaining intact and accessible off-channel habitats is critical to maintaining key habitats and food sources for juvenile salmonids. However, opportunities to protect high-quality off-channel habitats are limited because many habitats have already been converted to other land uses. In addition, the cost of protection can be high, but lower than the cost of restoration activities. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported.
Relative cost	Medium	Direct costs would primarily be associated with implementing regulatory programs and acquiring land. The medium rating reflects the relative cost of protection and the level of effort needed to achieve a medium potential for improvement rating. The indirect costs would be associated with the foregone opportunity to convert the land to agricultural, residential, commercial, or industrial uses. Indirect costs to local economies are assumed to be minor given the limited feasibility of protecting lands.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Restore off-channel habitat by breaching (or lowering) dikes and levees where possible.

Threat this action would address		**Dikes and filling.** Restoring off-channel areas would reclaim habitat that is important to salmonids. In most cases, project benefits would accrue over relatively long periods of time.
Threat priority[1]	High	This threat is linked to many limiting factors, including reduced macrodetritus inputs, sediment/nutrient-related estuary habitat changes, bankfull elevation changes, sediment/nutrient-related plume changes, and exotic plants. The high designation is suggested because this threat is a primary cause of both top-priority and high-priority limiting factors.
Feasibility of action[2]	Medium	Restoration of off-channel habitat by breaching or lowering dikes and levees is challenging for several reasons. Breaching often requires the cooperation of many landowners, it may fundamentally alter land uses, and the associated habitat restoration is expensive. The feasibility of this action is considered to be medium because of the inherent challenges associated with identifying opportunities that meet both biological and social needs.
Key assumptions		Evaluation of this management action assumes that additional opportunities to restore off-channel habitats can be developed through long-term outreach and improved landowner relationships.
Potential for improvement in survival[3]	High (high threat priority and medium feasibility of action)	Dikes and filling are believed to be responsible for several limiting factors in the estuary. However, there are limited opportunities to restore off-channel habitats that have not been filled or where filling would not preclude existing uses. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported.
Relative cost	Medium	Direct costs would primarily be associated with program infrastructure needs and construction and monitoring. The medium rating reflects the increased cost of restoration over protection and the level of effort needed to achieve a medium potential for improvement rating. The indirect costs would be associated with the foregone opportunity to use the land for agriculture or residential, commercial, or industrial development. Indirect costs to local economies are assumed to be minor given the limited feasibility of restoring off-channel habitats.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Remove tide gates where appropriate.

Threat this action would address		**Dikes and filling.** Restoring off-channel areas would reclaim habitat that is important to salmonids. In most cases, project benefits would accrue over relatively long periods of time.
Threat priority[1]	High	This threat is linked to many limiting factors, including reduced macrodetritus inputs, sediment/nutrient-related estuary habitat changes, bankfull elevation changes, sediment/nutrient-related plume changes, and exotic plants. The high designation is suggested because this threat is a primary cause of both top-priority and high-priority limiting factors.
Feasibility of action[2]	Medium	Restoration of off-channel habitat through removal of tide gates is challenging for several reasons. Removing tide gates often requires the cooperation of many landowners, it may fundamentally alter land uses, and the associated habitat restoration is expensive. The feasibility of this action is considered to be medium because of the inherent challenges associated with identifying opportunities that meet both biological and landowner needs.
Key assumptions		Evaluation of this management action assumes that additional opportunities to restore off-channel habitats can be developed through outreach and improved landowner relationships.
Potential for improvement in survival[3]	Medium (high threat priority and medium feasibility of action)	Dikes and filling are believed to be responsible for several limiting factors in the estuary. However, there are limited opportunities to restore off-channel habitats that have not been filled or where removing tide gates would not preclude existing uses. A habitat connectivity index would be useful in the evaluation of potential projects. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported.
Relative cost	Medium	Direct costs would primarily be associated with development of program infrastructure, construction associated with tide gate removal and related levee activities, and monitoring. The medium rating reflects the increased cost of restoration over protection and the level of effort needed to achieve a medium potential for improvement rating. Indirect costs would be associated with the foregone opportunity to use the land for agriculture or residential, commercial, or industrial development. Indirect costs to local economies are assumed to be minor given the limited feasibility of restoring off-channel habitats.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Upgrade tide gates where (1) no other option exists, (2) structures can provide appropriate access for juveniles, and (3) ecosystem function would be improved over current conditions.

Threat this action would address		**Dikes and filling.** Restoring off-channel areas would reclaim habitat that is important to salmonids. In most cases, project benefits would accrue over relatively long periods of time.
Threat priority[1]	High	This threat is linked to many limiting factors, including reduced macrodetritus inputs, sediment/nutrient-related estuary habitat changes, bankfull elevation changes, sediment/nutrient-related plume changes, and exotic plants. The high designation is suggested because this threat is a primary cause of several high-priority limiting factors.
Feasibility of action[2]	Low	Tide gate operations and maintenance are typically the responsibility of the landowner. Circumstances that allow improved hydraulic conditions and access for juveniles are limited, especially for improved access. The feasibility of this action is considered to be low because of the inherent challenges of improving access for juveniles by upgrading tide gates.
Key assumption		Evaluation of this management assumes that in some limited circumstances, improvements to tide gates may increase access for juveniles and hydrology.
Potential for improvement in survival[3]	Low (high threat priority and low feasibility of action)	The potential for improvement in survival is considered to be low because of the limited circumstances where tide gate improvements would substantially improve access to off-channel habitats for juveniles. A habitat connectivity index would be useful in the evaluation of potential projects. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported.
Relative cost	Low	Direct costs would primarily be associated with the actual costs of tide gate retrofitting activities. In cases where hydraulics are improved enough to warrant additional dikes to protect adjacent properties, costs would be higher. The low rating for direct cost reflects the limited opportunities that meet access and hydrology criteria. Indirect costs of tide gate retrofitting are limited to the potential interruption of current land uses (if increased saltwater flooding affects adjacent land uses). Given these limits, it is likely that actual economic effects would be low.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Increase spring flows to enhance the transport of sand and gravels through the estuary, plume, and ocean nearshore.

Threat this action would address		**Impaired sediment transport.** The transport of sand and gravel from upstream and estuary sources helps maintain salmonid habitats and contributes to turbidity that helps shelter salmonids from predation. Spring freshets are important habitat-shaping events for the estuary, plume, and near-shore areas.
Threat priority[1]	High	This threat is linked to several limiting factors, including flow-related estuary changes and flow-related plume changes. The high designation is suggested because this threat is a primary cause of both top-priority and high-priority limiting factors.
Feasibility of action[2]	Low	Constraints on hydrosystem operations prevent the return to a natural hydrograph in the estuary. However, it may be possible to adjust hydrosystem operations incrementally to increase salmonid habitat opportunity in the estuary. Implementation of this action would be limited by international treaties, the need for flood control, fish management objectives, and power management.
Key assumption		Evaluation of this management action assumes that small to moderate changes in the magnitude, frequency, and timing of flows, especially spring freshets, would improve sediment transport-related habitat opportunity in the estuary.
Potential for improvement in survival[3]	Low (high threat priority and low feasibility of action)	Impacts resulting from sediment transport are believed to be significant, and it is likely that managing the hydrosystem to mimic the historical hydrograph—and thus enhance the transport of sediment to the estuary—would improve salmonid survival rates. However, there are significant barriers to managing flows in the estuary to mimic the historical hydrograph. As a result, the potential for improvement in survival is estimated to be low. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported. Stream-type juveniles rearing in the estuary and plume would be expected to benefit from factors related to increased turbidity for protection from predators.
Relative cost	Medium	Direct costs would primarily be associated with U.S. and Canadian programs responsible for establishing Columbia River flows. Cost would primarily be a function of technical and policy analysis within existing programs. The indirect costs of a more natural hydrograph in the estuary have the potential to be extremely high; however, foregone electricity production, gas supersaturation issues, the need for flood control, and legal constraints place limits on the potential for increases in estuary flow. Given these limits, it is likely that actual economic effects would be only moderate. Indirect costs would include, but not be limited to, higher prices for domestic, commercial, and industrial electricity and foregone opportunities to sell wholesale electricity to markets.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.

Threat this action would address		**Impaired sediment transport.** The transport of sand and gravel from upstream and estuary sources helps maintain salmonid habitats and contributes to turbidity that helps shelter salmonids from predation. Dredge operations effectively reduce available sand for potential transport through the estuary, plume, and nearshore.
Threat priority[1]	High	This threat is linked to several limiting factors, including flow-related estuary changes and flow-related plume changes. The high designation is suggested because this threat is a primary cause of two top-priority limiting factors.
Feasibility of action[2]	Low	Since the 1870s, dredging activities have been occurring to provide sufficient draft for ships entering the Columbia River. Between 4 and 5 million cubic yards of sand are dredged and disposed of each year. The combined effects of reduced upstream sediment entrapment and the export of sand from dredging are unknown. Deposition of dredge materials is regulated by the U.S. Environmental Protection Agency using established criteria to reduce environmental effects. The feasibility of this management action is rated low because opportunities to beneficially use the dredged material are limited.
Key assumption		Evaluation of this management action assumes that opportunities to beneficially use dredged materials exist and that beneficial use of dredged material would have a positive effect on sediment transport processes.
Potential for improvement in survival[3]	Medium (high threat priority and low feasibility of action)	While sediment transport processes are important determinants of estuary and plume habitats, it is unknown how the loss of sediment supplies from upstream reservoir entrapment and the export of dredged material influence habitat-forming processes. However, scientists do understand that sediment exports from the estuary are three times as much as sediment inputs into the estuary. The potential for improvement in survival is predicted to be medium because there are limited alternatives to the release of dredged materials. New alternatives should be studied and evaluated with the goal of learning whether these materials can be effectively recycled to reduce the net loss to the estuary. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported.
Relative cost	Medium	Direct costs would primarily be associated with the added costs of research and implementation of efforts to reduce the net export of sand from the estuary. Costs could increase significantly if viable alternatives to the export of sand and gravels were identified and implemented. Indirect costs are assumed to be relatively low given the low feasibility of this management action. If dredging costs increased, they would be passed along through the shipping industry to industry and consumers.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Increase macrodetrital inputs and other historical food sources in the estuary to compensate for reservoir phytoplankton production, which is a permanent ecosystem alteration.

Threat this action would address		**Reservoir phytoplankton production**. Since the construction of hydrosystem reservoirs in the Columbia River, the estuary has shifted from its traditional macrodetritus-based food web—produced from vegetated wetlands—to a microdetritus-based food web. This shift represents a fundamental change to the estuarine ecosystem and to salmonids.
Threat priority[1]	High	This threat is a primary cause of a top-priority limiting factor: increased microdetrital inputs.
Feasibility of action[2]	Low	The production of reservoir phytoplankton is a permanent ecosystem alteration. Mitigation of this threat may be the only feasible solution.
Key assumption		Evaluation of this management action assumes that no actions other than mitigation can help reduce the threat.
Potential for improvement in survival[3]	Low (high threat priority and low feasibility of action)	The potential for improvement in survival is considered to be low because reservoir phytoplankton production is a permanent ecosystem alteration in the estuary. Increasing macrodetritus inputs by providing access to off-channel habitats represents one plausible mitigation solution. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported.
Relative cost	Low	No direct costs. Mitigation potential is not factored into this estimate. No indirect costs. Mitigation potential is not factored into this estimate.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Upgrade up-river irrigation structures using water conservation best management practices to reduce evaporation and conveyance losses to improve estuary instream flows.

Threat this action would address		**Water withdrawal.** Instream flows in the estuary are important for salmonids because they maintain habitat-forming processes and conditions in the estuary and plume. Irrigation is the primary cause of reductions in the average annual instream flows in the estuary. Losses include spray evaporation, canopy loss, wind drift, runoff, and deep percolation.
Threat priority[1]	Medium-high	This threat is linked to many limiting factors, including flow-related estuary habitat changes, flow-related changes to off-channel habitat, flow-related plume changes, and reduced macrodetritus inputs. The medium-high designation is suggested because this threat is a secondary cause of four top-priority limiting factors.
Feasibility of action[2]	Medium	Between 0 and 45 percent of irrigation water is not consumed by crops and returns as instream flow. Actual consumption is a factor of crop type, soils, and the type of irrigation system being used. Irrigation efficiency can be improved through equipment upgrades, active maintenance, education on seasonal crop evapotranspiration rates, scheduling irrigation in response to crop demand, and ground-truthing soil moisture.
Key assumptions		Evaluation of this management action assumes that increased conservation practices can help reduce current irrigation water needs and reduce the demand for additional water over time.
Potential for improvement in survival[3]	Medium (medium-high threat priority and medium feasibility of action)	Agricultural irrigation represents the largest consumptive user of water in the Columbia River basin. If implemented, this action would help ensure that water used for agriculture would be limited to the water needed for crop production and that the least amount feasible would be lost to evaporation or other losses. The potential for improvement is reduced by potentially new consumption by junior downstream water rights. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported. Stream-type salmonids also could benefit from increased flows in the plume.
Relative cost	Medium	Direct costs would primarily be associated with programs to assist farmers in underwriting the capital costs of upgrading equipment. The medium estimate is based on the large number of irrigation systems in the basin and the significant undertaking that would be necessary to reduce losses. The indirect costs to local economies of implementing best management practices in irrigation systems are assumed to be low to negligible.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Implement water conservation best management practices for public and private water purveyors.

Threat this action would address		**Water withdrawal.** Instream flows in the estuary are important for salmonids because they maintain habitat-forming processes and conditions in the estuary and plume. Public and private use of water is extremely important in Columbia River tributaries but also contributes to reduced estuary flows. The growing human population in the basin represents an ever-increasing threat to salmonids.
Threat priority[1]	Medium-high	This threat is linked to many limiting factors, including flow-related estuary habitat changes, flow-related changes to off-channel habitat, flow-related plume changes, and reduced macrodetritus inputs. The medium-high designation is suggested because this threat is a secondary cause of four top-priority limiting factors.
Feasibility of action[2]	Medium	Water supply for residential, municipal, and industrial uses represents a fraction of the 16 percent mean flow reduction in the Columbia River since the 1900s. Available conservation techniques would reduce consumptive losses. Some conservation practices currently are required, while others would be more costly to purveyors than alternative sources of water might be.
Key assumption		Evaluation of this management action assumes that conservation efforts beyond legal requirements could be in the best interests of the public if the additional instream flow were to benefit salmonids.
Potential for improvement in survival[3]	Low	Both long-term water conservation education and new funding for conservation programs would be needed for this management action to be effective. The potential for improvement in survival is limited because the use of water for public and private consumption represents a small (but growing) fraction of reduced instream flows. This action calls for the efficient use of water as consumption increases over time. Although the threat priority and feasibility of action are rated medium-high and medium, respectively, a low survival improvement score is suggested because the actual savings in instream flows that would result from conservation activities would be relatively low compared to irrigation conservation potential. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported. Stream-type salmonids also could benefit from increased flows in the plume.
Direct cost (estimated)	Low	Direct costs would primarily be associated with education and outreach and increased funding to programs that assist in the implementation of conservation retrofits. Indirect costs would include local effects to the economy because conservation costs would be passed along to consumers.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Establish legal instream flows for the Columbia River and tributaries that would prevent further degradation of downstream ecosystems.

Threat this action would address		**Water withdrawal.** Instream flows in the estuary are important for salmonids because they maintain habitat-forming processes and conditions in the estuary and plume.
Threat priority[1]	Medium-high	This threat is linked to many limiting factors, including flow-related estuary habitat changes, flow-related changes to off-channel habitat, flow-related plume changes, and reduced macrodetritus inputs. The medium-high designation is suggested because this threat is a secondary cause of four top-priority limiting factors.
Feasibility of action[2]	Medium	Instream flow laws legally protect tributary and mainstem flows. The right has legal standing and is senior to predecessor water rights. Although some instream flows have been established in the Columbia River basin, others are needed. The feasibility of this action is medium in view of recent positive efforts in Washington State and elsewhere in the basin to establish instream flows; however, the expanding human population in the region will need additional water, and it is likely that these needs will reduce instream flows.
Key assumption		The evaluation of this management action assumes that establishing a legal instream flow would protect flows entering the estuary in the future.
Potential for improvement in survival[3]	Medium (medium-high threat priority and medium feasibility)	Some legal instream flows have been established, and others are in the process of being established. But the setting of instream flows is challenging and can often take years. In some cases instream flows never get set at all. The medium rating for potential for improvement in survival recognizes the medium-high threat priority and medium feasibility of this management action. However, over the long term it will be difficult to protect instream flows because of human population growth in the basin. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported. Stream-type salmonids also could benefit from increased flows in the plume.
Relative cost	Medium	Direct costs would primarily be associated with public education and outreach, community-based watershed planning, technical support, and legal assistance. Direct costs are assumed to be medium because of the grassroots-level effort that is required to support instream flow regulations. The indirect costs of establishing instream flow regulations in the Columbia River basin would increase over time. At the time the instream flow is adopted, the opportunity costs associated with leaving water in streams would be relatively low; however, as demand for water increases, the opportunity costs would grow significantly and demand for water would increase in the market.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Incorporate water availability analysis in land use planning activities to ensure efficient use of water.

Threat this action would address		**Water withdrawal.** Population growth in the Columbia River basin is expected to continue to increase through the twenty-first century, with commensurate demands for water.
Threat priority[1]	Medium-high	This threat is linked to many limiting factors, including flow-related estuary habitat changes, flow-related changes to off-channel habitat, flow-related plume changes, and reduced macrodetritus inputs. The medium-high designation is suggested because this threat is a secondary cause of four top-priority limiting factors.
Feasibility of action[2]	Medium	Most land use planning does not proactively consider water availability as a central element in growth management. Constraints to implementing this action include the legal constructs of Western water law and societal views of property rights versus public rights. The medium score is predicated on a long-term education and outreach process that would help establish a basis for recognizing water as a fundamental driver of growth management.
Key assumption		Evaluation of this management action assumes that effective use of water for residential, commercial, and industrial purposes throughout the basin would help preserve the historical timing, magnitude, and duration of flows entering the estuary.
Potential for improvement in survival[3]	Low	Most benefits of this management action would occur over a long period of time. It is likely that the demand for water will continue to grow as the human population in the region increases. The potential for improvement in survival is related to the degree to which development and the associated demands for additional water occur in the geographical areas where water is relatively available. The low score is based on the assumption that this action addresses a medium-high threat priority and has medium feasibility; actual improvements to the estuary would be minor compared to Columbia River tributaries because smaller tributaries are more sensitive to higher water withdrawals. Ocean- and stream-type salmonids would benefit from protected instream flows. Much of this benefit would occur in tributaries, but the timing and magnitude of estuary and mainstem flows also would be improved.
Relative cost	Medium	Direct costs would primarily be associated with public programs that manage land use. Direct costs would be high because long-term benefits from this action would require significant efforts over time. Cost would primarily be a function of planning, education, and technical costs associated with mapping and analyzing instream flow and water supply needs. Indirect costs would be associated with foregone opportunities to intensively develop some lands in the Columbia River basin. Indirect costs are assumed to be low because of the low potential for improvement in survival. If this action were fully implemented, indirect costs would be high.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Implement stormwater and runoff best management practices in cities and towns.		
Threat this action would address		**Urban and industrial practices.** Population growth in the Columbia River basin is expected to continue through the twenty-first century, and this growth will continue to influence the hydrology and water quality in the estuary.
Threat priority[1]	Medium-high	This threat is linked to several limiting factors, including temperature, short-term toxicity, and bioaccumulation toxicity. The medium-high designation is suggested because this threat is a primary cause of two high-priority limiting factors and a secondary cause of one additional limiting factor.
Feasibility of action[2]	Medium	The feasibility of this action is considered to be medium because cities and towns generally have stormwater programs designed to reduce impacts. However, not all cities and towns have transitioned to best management practices and may contribute disproportionally to negative water quality and hydrology impacts. The feasibility of this management action is considered to be medium because some cities lack the resources or desire to implement or enforce best management practices.
Key assumption		Evaluation of this management action assumes that implementing best management practices would markedly improve conditions and provide a net benefit to salmonids in the estuary through a more normal hydrograph and reduced pollution; however, it is assumed that these changes would occur slowly over time.
Potential for improvement in survival[3]	Medium (medium-high threat priority and medium feasibility of action)	Stormwater programs are already in place in some cities and towns in the Columbia River basin, and the effects of stormwater runoff are well studied. However, the beneficial effects of improved stormwater practices relate only to new development and do not offset the full impact of additional impervious surface areas associated with new development. Both ocean- and stream-type salmonids would benefit from a more natural hydrograph and reduced pollution; however, ocean types could benefit more than stream types because of their longer residency in the estuary.
Relative cost	Medium	Direct costs would primarily be related to the technical and planning needs associated with regulatory programs. Direct costs would be high because of the scale of the effort (in cities and towns throughout the Columbia River basin) and increased development costs. The indirect costs would primarily be associated with increased development costs and their effects on local economies.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Protect intact riparian areas and restore riparian areas that are degraded.

Threat this action would address		**Urban and industrial practices.** Riparian areas adjacent to waterways in the greater Portland, Vancouver, Longview, and Astoria areas have been degraded by a variety of residential, commercial, and industrial practices. In some cases, riparian areas have functionally been converted to other uses that will remain for the foreseeable future. In other cases, riparian areas could be restored and gain ecological function. Some intact riparian areas need additional protection.
Threat priority[1]	Medium-high	This threat is linked to several limiting factors, including temperature, short-term toxicity, and bioaccumulation toxicity. The medium-high designation is suggested because this threat is a primary cause of two high-priority limiting factors and a secondary cause of one additional limiting factor.
Feasibility of action[2]	Medium (medium-high threat priority and medium feasibility of action)	Levels of protection vary across the lower Columbia region. In some cases, cities and counties are protected through regulatory mechanisms such as growth management or shoreline rules. The feasibility of uniformly implementing protective buffers to riparian areas is considered to be medium. Regulatory tools can be effective but require broad public support over time. In addition, restoration projects are under way and will continue into the future; however, they are expensive and may take decades to provide their full benefit to tributaries directly entering the estuary.
Key assumption		Evaluation of this management action assumes that comprehensive protection and restoration of riparian habitats would occur concurrently as population growth continues at a high rate.
Potential for improvement in survival[3]	Medium	Riparian areas in the estuary and in lower Columbia River tributaries have been affected by the largest population growth of anywhere in the Columbia River basin. Protection of intact riparian areas is critical as new homes, businesses, and industry expand. Restoration of impaired riparian areas in priority reaches can help reduce temperatures and reduce fine sediment delivery. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported.
Relative cost	Medium	Direct costs would primarily be associated with program infrastructure, acquisition costs, and restoration costs. To achieve the medium potential for improvement in survival, the level of effort would be significant and would be relatively expensive. Indirect costs would be associated with foregone opportunities to continue existing land use practices or develop new ones. Indirect costs are considered to be minor because of existing protections that generally protect riparian areas.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Locate sources of industrial and commercial pollutants and take steps to reduce inputs.

Threat this action would address		**Urban and industrial practices.** Industrial and commercial pollutants, including PCBs and PAHs, are found near Portland, Vancouver, Longview, and Astoria. Increases in water temperature, the release of toxic contaminants, and nutrient loading in the estuary have reduced habitat capacity and decreased the fitness level of salmonids.
Threat priority[1]	Medium-high	This threat is linked to several limiting factors, including temperature, short-term toxicity, and bioaccumulation toxicity. The medium-high designation is suggested because this threat is a primary cause of two high-priority limiting factors and a secondary cause of one additional limiting factor.
Feasibility of action[2]	Medium	While some discharges of industrial and commercial pollutants are permitted, others are not. The feasibility of this action is considered to be medium because efforts are under way to reduce industrial and commercial pollutants and there is potential to reduce point-source emissions.
Key assumption		Evaluation of this management action assumes that releases of industrial and commercial pollutants into the estuary would be reduced over time.
Potential for improvement in survival[3]	Medium (medium-high threat priority and medium feasibility of action)	The estuary has been affected by historical and current releases of toxic contaminants. Recent studies have demonstrated significant juvenile mortality in the estuary as a result of toxic contaminants. Both ocean- and stream-type salmonids would benefit from reduced exposure to contaminants; however, ocean types could benefit more than stream types because of their longer residency in the estuary.
Relative cost	High	Direct costs would primarily be associated with the application of best management practices, including increased monitoring and application of advanced technologies. Direct costs are estimated to be high because of the potentially large capital costs of industrial plant upgrades and enhanced monitoring. Indirect costs of the action would be associated with the increased financial burden on commercial and industrial plants in lower Columbia River cities and the economies that depend on their products.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Monitor the estuary for contaminants and restore contaminated sites where appropriate.

Threat this action would address		**Urban and industrial practices.** Industrial and commercial pollutants, including PCBs and PAHs, are found near Portland, Vancouver, Longview, and Astoria. Increases in water temperature, the release of toxic contaminants, and nutrient loading in the estuary have reduced habitat capacity and decreased the fitness level of salmonids.
Threat priority[1]	Medium-high	This threat is linked to several limiting factors, including temperature, short-term toxicity, and bioaccumulation toxicity. The medium-high designation is suggested because this threat is a primary cause of two high-priority limiting factors and a secondary cause of one additional limiting factor.
Feasibility of action[2]	Medium	Ongoing monitoring provides vital data needed to understand the toxic contaminant problem and identify potential restoration solutions. The feasibility of this action is rated medium because monitoring activities are already occurring; however, actual restoration of contaminated sites is expensive and technically challenging in many cases.
Key assumption		Evaluation of this management action assumes that hot spots and sources of contamination would be identified through continued and enhanced monitoring of toxic contaminants in the estuary.
Potential for improvement in survival[3]	Medium (medium-high threat priority and medium feasibility of action)	The estuary has been affected by historical and current releases of toxic contaminants. Recent studies have demonstrated significant juvenile mortality in the estuary as a result of toxic contaminants. Additional analysis could help identify candidate restoration sites. Both ocean- and stream-type salmonids would benefit from a more natural hydrograph and reduced pollution; however, ocean types could benefit more than stream types because of their longer residency in the estuary.
Relative cost	Medium	Direct costs would primarily be associated with monitoring and restoration activities. It is assumed that a significant level of cleanup would be required to achieve medium potential for improvement in survival, and that direct costs would be commensurate. Indirect costs of the action would be associated with the increased financial burden on commercial and industrial plants in lower Columbia River cities and the economies that depend on their products.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Study and mitigate the effects of entrapment of sediment in reservoirs.

Threat this action would address		**Entrapment of sediment in reservoirs.** Fine sediment, sand, and gravel are deposited behind slow-velocity impoundments in the Columbia River, and their transport into the estuary, nearshore, and plume has been reduced. This alters habitat-forming processes.
Threat priority[1]	Medium-high	This threat is linked to two limiting factors: sediment/nutrient-related estuary habitat changes and flow-related plume changes. The medium-high designation is suggested because this threat is a primary contributor to both top-priority and high-priority limiting factors.
Feasibility of action[2]	Low	Entrapment of sediment in reservoirs is a permanent change in the ecosystem, and the feasibility of reducing the entrapment of upstream sediment is extremely low. Research is needed to identify the magnitude of the threat and potential solutions or mitigation measures.
Key assumption		Evaluation of this management action assumes that entrapment of sediment in reservoirs is a permanent change in the ecosystem.
Potential for improvement in survival[3]	Low (medium-high threat priority and low feasibility of action)	The potential for improvement in survival is considered to be low or non-existent because there are no apparent technical solutions to this threat. Mitigation is recommended but not factored into the potential for improvement in survival.
Relative cost	Low	Direct costs would be those associated with research to help determine the magnitude of the threat and potential solutions. No indirect costs.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Implement pesticide and fertilizer best management practices to reduce estuary and upstream sources of toxic materials entering the estuary.

Threat this action would address		**Agricultural practices.** Water-soluble contaminants such as simazine, atrazine, chlorpyrifos, metolachlor, diazinon, and carbaryl enter the estuary as a result of tributary and upstream agricultural practices. DDT and PCBs have been detected at elevated levels in the estuary. Contaminants have the potential to cause mortality through bioaccumulation or short-term toxicity.
Threat priority[1]	Medium-high	This threat is linked to two limiting factors: bioaccumulation and short-term toxicity. The medium-high designation is suggested because this threat is a primary contributor to a high-priority limiting factor and a secondary contributor to a medium-priority limiting factor.
Feasibility of action[2]	Medium	Impacts from fertilizers and pesticides applied through agricultural practices have lessened dramatically since the 1950s as a result of new technologies and practices, together with improved understanding and regulation. The medium rating is suggested because of the general trend of improved agricultural practices based on new application technologies, new products, continually evolving regulations, and a better understanding of fertilizers and pesticides by farmers.
Key assumption		Evaluation of this management action assumes that additional benefit to salmonids can be realized through continued efforts by farmers, chemical manufacturers, and regulatory programs to reduce impacts from fertilizers and pesticides.
Potential for improvement in survival[3]	Medium (medium-high threat priority and medium feasibility of action)	The use of many toxic chemicals already has been significantly reduced. The potential for improvement in survival is expected to improve over a relatively long period of time as agricultural practices improve. Ocean-type salmonids would be most likely to benefit from reductions in both acute and chronic exposures to toxic contaminants; stream-type salmonids would be likely to benefit from reduction in acute exposures to toxic contaminants.
Relative cost	Medium	Direct costs would primarily be associated with chemical manufacturer research and regulatory program testing, education, and enforcement. The cost of pesticide and fertilizer applications would increase. Direct costs are estimated to be medium given the number of agricultural operations in the Columbia River basin. Indirect costs would be incurred regionally in the form of higher food prices. Indirect costs are estimated to be low to moderate, which reflects the speed with which changes can be expected to occur.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Manage the hydrosystem to reduce reservoir surface heating.		
Threat this action would address		**Reservoir heating.** Low-velocity flows and broad surface area exposure in reservoirs increase the temperature of flows in the estuary.
Threat priority[1]	Medium-high	This threat is linked to increased temperatures in the estuary. The medium-high designation is suggested because this threat is a primary contributor to a single high-priority limiting factor.
Feasibility of action[2]	Low	Elevated temperatures that result from reservoir heating are difficult to reduce; however, some management techniques may help keep temperatures as low as possible. Temperatures may be influenced by the volume and speed of flows through the hydrosystem and the source of those flows. Sources of flow are important to temperature management because some impoundments have more cool waters than others.
Key assumption		Evaluation of this management action assumes that there is some potential to alter management practices in the hydrosystem to reduce flow temperatures, or that a commensurate level of mitigation in tributaries occurs to reduce temperatures.
Potential for improvement in survival[3]	Low	International treaties, conflicting fish management objectives, the need for flood control, power management, and other factors constrain management of the hydrosystem to allow cooler flows entering the estuary. Ocean-type salmonids would be most likely to benefit from this management action because of their longer residencies in the estuary; however, stream-type salmonids displaying less dominant life history strategies also would be supported.
Relative cost	Low	Direct costs would primarily be associated with changes in hydrosystem operations. No mitigation activities are included in this estimate. The low relative cost is based on the potential level of change in hydrosystem operations. Cost would primarily be a function of foregone electricity generation and technical and policy analysis of threat reduction.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Protect and restore timberland riparian areas for shade and future wood sources.

Threat this action would address		**Increased flow temperatures as a result of timber practices.** Timber harvest within riparian areas has increased the temperatures of tributaries, which in turn warm flows entering the estuary. Columbia River temperatures measured at Bonneville Dam have been increasing since 1938. Occurrences of temperatures approaching the lethal threshold for salmonids have increased in frequency and duration over this time period.
Threat priority[1]	Medium-high	This threat is linked to increased temperatures identified in the estuary. The medium-high designation is suggested because this threat is a primary contributor to a single high-priority limiting factor.
Feasibility of action[2]	Medium	Protection of timberland riparian areas in estuary and upstream tributaries has occurred in some areas of the Columbia River basin. Efforts such as Forest & Fish in Washington State could serve as a model for protecting timberland riparian areas. Programmatic regulations that protect riparian areas are difficult to develop and can be expensive for property owners. Restoration of timberland riparian areas is labor intensive, and improvement may take decades. The medium score is based on both the recent examples of protection and restoration in contrast with potential costs to local economies and property owners.
Key assumption		Evaluation of this management action assumes that all timberland riparian areas in the Columbia River basin receive adequate levels of protection in perpetuity.
Potential for improvement in survival[3]	Medium (medium-high threat priority and medium feasibility of action)	Protection levels of timberland riparian areas throughout the Columbia River basin vary significantly. Although impacts of timber practices are somewhat high, implementation of this management action could be challenging because of foregone revenue costs. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported. Stream-type salmonids' shorter estuarine residency times would make them less likely to be affected by this management action than ocean types would.
Relative cost	High	Direct costs would primarily be to timber resource landowners through foregone revenue opportunities and the costs of restoration of riparian areas. It is assumed that direct costs would be very high if a medium potential for improvement in survival were to be achieved. Indirect costs to regional and local economies would be moderate. Indirect costs would include reduced timber for loggers, truck drivers, and mills, which can be locally important revenue generators. Potential increases in lumber prices could affect development sectors.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Remove jetties and navigational structures that have low navigational value but high impact on estuary circulation and/or juvenile predation effects.

Threat this action would address		**Jetties and navigational structures**. Extensive use of jetties and other navigational structures has altered sediment accretion and erosion processes, decreased sediment accretion in the marine littoral areas, and reduced flow circulation through shallow-water habitats in the estuary.
Threat priority[1]	Medium	This threat contributes to several limiting factors, including sediment/nutrient-related estuary habitat changes, sediment/nutrient-related plume habitat changes, and predation by exotic fish. The medium designation is suggested because this threat is a secondary or tertiary contributor to high-priority and lowest priority limiting factors.
Feasibility of action[2]	High	Only some of the thousands of jetties and navigational structures in the Columbia River estuary are necessary to maintain the shipping channel or protect property. Removal of superfluous structures generally is restricted only by cost and would be unlikely to affect property rights or the shipping industry. An accurate inventory of jetties and navigational structures and an analysis of their function would be needed to determine which structures are superfluous.
Key assumption		Evaluation of this management action assumes that an inventory of instream structures and analysis of their function would indicate that many jetties and navigational structures could be removed without compromising the shipping channel or protection of property.
Potential for improvement in survival[3]	Medium (medium threat priority and high feasibility of action)	Removing many instream structures would improve circulation in shallow-water habitats and eliminate some salmonid predator habitats. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported.
Relative cost	Medium	Direct costs would primarily be associated with an inventory of structures, analysis of their function, and their removal. The medium designation in the potential for improvement in survival rating assumes that a high level of effort would be needed to reduce instream structures. The indirect costs of inventorying, analyzing, and removing instream structures would be low. Removing structures could have a beneficial effect on local communities by stimulating local economies through contracting.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Manage smallmouth bass, walleye, and channel catfish to prevent increases in abundance.

Threat this action would address		**Altered predator/prey relationships.** Introductions of smallmouth bass, walleye, and channel catfish in the freshwater reaches of the estuary have increased predation on juvenile salmonids.
Threat priority[1]	Medium-low	This threat contributes to many limiting factors, although the management action addresses only the exotic fish limiting factor. The medium-low designation is suggested because this threat is a secondary contributor to a medium-priority limiting factor.
Feasibility of action[2]	Medium	The introduction of exotic fish may be irreversible. However, there are viable tools for managing smallmouth bass, walleye, and channel catfish, such as less restricted harvest management and habitat management. The medium feasibility of the action assumes that exotic fish introductions are likely irreversible and that warm-water fishers actively support continued fisheries at their present levels; however, management techniques could maintain populations at levels that reduce predation impacts to salmonids.
Key assumption		Evaluation of this management action assumes that maintaining warm-water species at current levels and preventing new introductions of exotic fish would have minor benefits to salmonids by reducing predation and competition.
Potential for improvement in survival[3]	Low	Ecosystem alterations by smallmouth bass, walleye, and channel catfish are relatively small in the estuary, as indicated by the medium-low threat priority. Although the feasibility of action is rated medium, the potential for improvement in survival is considered to be low because the contribution of the threat to limiting factors for juvenile salmonids is minor. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported.
Relative cost	Low	Direct costs would primarily be associated with programs by natural resource agencies to manage warm-water exotic species. Indirect costs would be limited because of presumed opposition to reductions in warm-water fisheries in the estuary.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Reduce the impacts on salmonids by pinnipeds.		
Threat this action would address		**Altered predator/prey relationships.** Pinniped predation on salmonids has been studied and shown to be relatively low; however, observations by commercial and sport fishers continue to document significant mortality of adult salmonids.
Threat priority[1]	Medium-low	This threat contributes to many limiting factors, although the management action relates only to the native pinnipeds limiting factor. The medium-low designation is suggested because this threat is a secondary contributor to a medium-priority limiting factor. .
Feasibility of action[2]	Low	The feasibility of reducing pinniped impacts on salmonids is considered to be low because pinnipeds are protected under the Marine Mammal Protection Act.
Key assumption		Evaluation of this management action assumes that mortality from pinniped predation can be reduced but that the extent of predation needs further study and documentation.
Potential for improvement in survival[3]	Low	Pinniped predation on adult salmonids has been studied but remains controversial because of conflicting opinions about mortality. The low score also reflects this uncertainty and the inherent challenges of reconciling conflicting regulatory protection mechanisms. Ocean- and stream-type salmonids would be likely to benefit equally from reduced pinniped predation.
Relative cost	Low	Direct costs would primarily be associated with additional study and documentation of predation effects on adult migrating salmonids. The indirect costs to local economies of reducing pinniped predation would be low. The commercial fishing industry likely would experience economic gains from reduced predation.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Reduce the abundance levels of Caspian terns nesting on islands created by disposal of dredged material.

Threat this action would address		**Altered predator/prey relationships.** Caspian tern predation represents a significant source of mortality for stream-type juveniles migrating to saltwater.
Threat priority[1]	Medium-low	This threat contributes to many limiting factors, although the management action relates only to Caspian terns. The medium-low designation is suggested because this threat is a secondary contributor to a medium-priority limiting factor.
Feasibility of action[2]	Medium	The feasibility score is predicated on the potential to further reduce tern predation on juvenile salmonids. Recent efforts have demonstrated success in the relocation of terns. Additional efforts should produce further increments of benefit.
Key assumption		Evaluation of this management action assumes that ongoing and new management actions directed to Caspian tern nesting habitat will continue to reduce salmonid mortality from tern predation.
Potential for improvement in survival[3]	Medium (medium-low threat priority and medium feasibility of action)	Caspian tern predation of migrating stream-type juvenile salmonids is well documented. In 1997, it was estimated that terns consume approximately 3 percent of estuarine smolt production. Recent management actions have helped reduce mortality, and efforts are ongoing. Stream-type salmonids would benefit most from this management action because of the timing of their out-migration and their preference for deep-channel habitats near tern nesting sites; however, ocean-type salmonids displaying less dominant life history strategies also would be supported.
Relative cost	Low	Direct costs would primarily be associated with the operations of Caspian tern management programs and on-the-ground efforts to relocate colonies. The indirect costs associated with this action would be low to non-existent. Reduction of tern-related mortality could have a net benefit for local economies that rely on commercial fishing as an industry.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Reduce the abundance levels of shad entering the estuary.		
Threat this action would address		**Altered predator/prey relationships.** Shad returns to the Columbia River number approximately 4 million annually. The impacts of shad in the ecosystem and on salmonids are poorly understood.
Threat priority[1]	Medium-low	This threat contributes to many limiting factors, although the management action relates only to shad. The medium-low designation is suggested because this threat is a secondary contributor to one of the lowest priority limiting factors.
Feasibility of action[2]	Low	Shad are thought to have permanently altered the estuary ecosystem and their complete removal from the estuary is neither practical nor feasible. Shad's effects on the estuary ecosystem are poorly understood, although there are new studies attempting to address the question. The low feasibility of action score is based on the assumption that additional study of shad and their effects on the estuary ecosystem may suggest new management techniques; however, it remains unlikely that significant changes are possible.
Key assumption		Evaluation of this management action assumes that additional research and study are needed to understand the magnitude of the limiting factor and identify potential solutions, but that solutions to the shad issue will occur over longer periods of time as shad's effects on salmonids are better understood.
Potential for improvement in survival[3]	Low (medium-low threat priority and low feasibility of action)	Effective management tools to limit shad productivity in the Columbia River basin are currently not available and are not likely to be identified for some time. Ocean-type salmonids would be most likely to benefit from this management action because of their longer estuarine residency times; however, stream-type salmonids displaying less dominant life history strategies could also benefit.
Relative cost	Low	Direct costs would primarily be associated with additional research and studies. The relatively low direct cost estimate does not reflect any on-the-ground management effort. No indirect costs have been identified. Given the great abundance of shad, recreational fishers would be unlikely to be affected even if shad numbers were reduced by 25 percent.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Reduce the effects of vessel wake stranding in the estuary.		
Threat this action would address		**Ship wakes.** Wakes from deep-draft vessels traveling through the estuary wash subyearling salmonids onto shore, leaving them stranded. A 1977 study by the Washington Department of Fisheries determined that ship stranding is a significant cause of salmonid mortality.
Threat priority[1]	Medium-low	This medium-low designation is suggested because this threat is a primary contributor to stranding, a low-priority limiting factor.
Feasibility of action[2]	Low	Initial studies on vessel wake stranding indicate that stranding occurs as a result of a combination of factors, including beach slope, time of day, and vessel draft. The low feasibility of the action is based on the assumption that ship traffic will continue, modifications to ship hull design will not change, and the speed of ships traveling the estuary may be difficult to alter.
Key assumption		Evaluation of this management action assumes that options for addressing the limiting factor are limited and that the actual threat posed by vessel wake stranding is as yet undetermined.
Potential for improvement in survival[3]	Low (medium-low threat priority and low feasibility of action)	The extent of mortality caused by ship wake stranding is unknown. Studies in 1977 and 1994 (Bauersfeld 1977, Hinton and Emmett 1994) reached different conclusions, using different approaches. A soon-to-be-released study by the University of Washington and U.S. Army Corps of Engineers may provide further clarification of the issue. Ocean-type salmonids would be most likely to benefit from this management action because of their longer estuarine residency times, their relatively small size, and the habitats they prefer; however, stream-type salmonids displaying less dominant life history strategies could also benefit.
Relative cost	Low	Direct costs would primarily be associated with additional research and studies. The relatively low direct cost estimate does not reflect potential alterations to ship travel speeds, ship design consideration, or shoreline alterations (where appropriate). No indirect costs have been identified because of the uncertainty of this issue. If changes to the shipping industry resulted, there would be indirect costs at the local and regional scale because additional costs would be passed along to consumers.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Reduce the square footage of over-water structures in the estuary.		
Threat this action would address		**Over-water structures.** Over-water structures may provide habitats for predators and affect instream and shoreline plant communities. However, the total surface area of over-water structures in the estuary has not been quantified and the structures' case-by-case functions have not been analyzed.
Threat priority[1]	Medium-low	This threat is linked to sediment/nutrient-related estuary habitat changes and exotic fish. The medium-low designation is suggested because this threat is a tertiary contributor to a high-priority limiting factor and a secondary contributor to one of the lowest priority limiting factors.
Feasibility of action[2]	Medium	It is assumed that some over-water structures are more important than others and that removing superfluous or less useful structures would not have deleterious effects on adjacent land uses. Research is needed to determine the number and surface area of over-water structures in the estuary and the actual threats that such structures pose to salmonids.
Key assumptions		Evaluation of this management action assumes that over-water structures pose a threat to salmonids and that a fair number of over-water structures are no longer in use or have relatively minor value to owners.
Potential for improvement in survival[3]	Low	Although the threat priority and feasibility of action are rated medium-low and medium, respectively, the improvement in survival must be considered low (pending research and analysis) given the uncertainty about how much of a threat over-water structures actually pose to salmonids. Ocean-type salmonids would be most likely to benefit from this management action because of their preference for the shallow-water habitats where most structures are located; however, stream-type salmonids displaying less dominant life history strategies also would be supported.
Relative cost	Low	Direct costs would primarily be associated with additional research, inventory, and analysis of over-water structures. The removal of structures would generate significant direct costs to achieve a low potential for improvement in survival. Indirect costs would be associated with foregone opportunities to use in-channel property for residential, commercial, recreational, or industrial activities. Indirect costs are estimated to be relatively low but could increase substantially as implementation occurred.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities in the estuary.

Threat this action would address		**Dredging**. Annual dredge operations maintain a navigational channel that concentrates flows, alters tidal influences, reduces circulation patterns around the estuary, and releases toxic contaminants from substrates. Dredging activities can result in deposited contaminants being disturbed and redistributed throughout the estuary and nearshore.
Threat priority[1]	Medium-low	This medium-low priority threat is a primary contributor to one of the lowest priority limiting factors.
Feasibility of action[2]	Low	Dredging activities have been occurring since the 1870s to provide sufficient draft for ships entering the Columbia River. Between 4 and 5 million cubic yards of sand are dredged and disposed of each year. The feasibility of reducing effects from dredge activities is considered to be low because of ongoing maintenance needed to keep the channel to specifications for ships.
Key assumption		Evaluation of this management action assumes that dredging can be conducted in a way that reduces its impacts and that mitigation activities can help offset changes to the estuary caused by dredging.
Potential for improvement in survival[3]	Medium (medium-low threat priority and low feasibility of action)	Continued dredge operations represent a physical change to the Columbia River estuary; however, potential for improvement in survival is possible through improved dredging practices and mitigation activities. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies also would be supported.
Relative cost	Medium	Direct costs would primarily be associated with improved operations and offsite mitigation activities. Indirect costs would include increased costs associated with shipping activities and ripple effects through the economy. Actual indirect costs would likely be medium because of the relatively small direct costs to a large industry.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Implement best management practices to prevent new introductions of invertebrates in the estuary.

Threat this action would address		**Ship ballast practices.** Ship ballast water is responsible for the introduction of exotic invertebrates in the estuary. Once introduced, these invertebrates represent a permanent alteration of the ecosystem. The effects of these introductions are poorly understood.
Threat priority[1]	Low	This threat is a primary contributor to one of the lowest priority limiting factors: introduced invertebrates.
Feasibility of action[2]	Low	Improvements in ship ballast practices have already been implemented by the industry as a result of new regulations, and stricter regulations are currently being debated at the federal level. The feasibility of reducing effects from ship ballast practices is considered to be low because of the inherent challenge of managing ballast water containing organisms from other ecosystems.
Key assumption		Evaluation of this management action assumes that improved ship ballast practices would help prevent further degradation of the estuary ecosystem.
Potential for improvement in survival[3]	Low (low threat priority and medium feasibility of action)	Current understanding of how the estuary ecosystem is affected by exotic invertebrate introductions is very limited. Additional research should be initiated to help scientists learn more about the effects of alterations to the ecosystem. Ocean-type salmonids would be most likely to benefit from this management action; however, stream-type salmonids displaying less dominant life history strategies would also benefit.
Relative cost	Low	Direct costs would primarily be associated with new ballast water practices, monitoring, and the provision of technical support for improved practices by regulatory agencies. Indirect costs would include increased costs associated with shipping activities and ripple effects through the economy. Actual indirect costs would likely remain low because of the relatively small direct costs to a large industry.

TABLE 5-2 (CONTINUED)
Evaluation of Potential Management Actions

Management Action: Increase the effectiveness of aquatic noxious weed laws through education, monitoring, and enforcement.

Threat this action would address		**Altered predator/prey relationships.** Exotic plants in the estuary are a threat because they often out-compete native plants and change the structure of plant communities. The resulting habitat frequently does not provide the same food or shelter for other species, including salmonids. Such introductions represent permanent alterations to the estuary ecosystem.
Threat priority[1]	Medium-low	This threat contributes to many limiting factors, including native birds, native pinnipeds, exotic plants, introduced invertebrates, and exotic fish. The medium-low designation is suggested because this threat is a secondary or tertiary contributor to several medium- and low-priority limiting factors.
Feasibility of action[2]	Medium	Education, outreach, and monitoring can help prevent further introductions of exotic plants. However, controlling existing infestations of certain species is functionally impossible once the species are established. Although landowners are the most important agents in preventing and controlling exotic plant infestations, landowner education is a significant task that requires a large effort.
Key assumption		Evaluation of this management action assumes that aquatic noxious weeds have a negative effect on the estuary ecosystem and that they likely affect juvenile salmonids by causing food webs to deteriorate.
Potential for improvement in survival[3]	Low (medium-low threat priority and medium feasibility of action)	There are inherent challenges in controlling some infestations. Prevention of new introductions is a high priority and can be accomplished through education, outreach, and monitoring activities. The low score reflects the potential for protection and the significant level of effort needed to control current infestations. The low score also underscores the need to better inventory existing infestations and study their effects on the estuary ecosystem. Ocean-type salmonids would be most likely to benefit from this management action because of their association with shallow-water habitats; however, stream-type salmonids displaying less dominant life history strategies would also benefit.
Relative cost	Low	Direct costs would primarily be associated with education, outreach, monitoring, and enforcement. Direct costs also would include significant resources to control existing infestations where landowner costs exceeded reasonable efforts. The indirect costs of managing exotic plant introductions would be negligible. The horticulture industry could be affected by the foregone opportunity to sell exotics.

[1] See Table 4-2, Prioritization of Threats to Ocean- and Stream-Type Salmonids.

[2] High = Implementation of the management action is possible within reasonable constraints.
Medium = Partial implementation of the management action is possible within reasonable constraints.
Low = Some part of the management action is possible within reasonable constraints.

[3] High = Given the threat priority, feasibility of action ratings, and key assumption, the action is assumed to result in large improvements.
Medium = Given the threat priority, feasibility of action ratings, and key assumption, the action is assumed to result in moderate improvements in survival

Low = Given the threat priority, feasibility of action ratings, and key assumption, the action is assumed to produce small improvements in survival.

Prioritization of Management Actions

If the majority of the management actions in Table 5-2 were fully implemented, collectively they would improve conditions in the estuary for upstream ESUs. On the other hand, no single management action by itself would be likely to improve the estuary ecosystem. This suggests that, to improve conditions for upstream ESUs, it will be necessary to implement as many of the 31 potential management actions as possible. Therefore, Table 5-3 groups potential management actions into categories according to each action's cost and potential to improve survival. Actions with similar ratios of survival improvement to cost are grouped together, and groupings have been arranged to indicate priority.

Caution should be exercised regarding the meaning of priority in Table 5-3. Although the literature provides a strong base for identifying limiting factors and threats, it offers considerably less support for the identification of management actions. This means that, of necessity, attempts to estimate survival improvements and costs must rely on assumptions about details that cannot be accurately predicted at this level of planning. As a result, Tables 5-2 and 5-3 are perhaps most useful when considered as a set of assumptions about the potential of various actions to improve the survival of upstream ocean- and stream-type salmon and steelhead. Specific details about actions, including their cost and feasibility, must be analyzed at the program level and in close coordination with implementing agencies, organizations, and businesses.

Priority 1 Actions

Priority 1 actions include all potential management actions that have a higher survival rating than cost rating. These actions would yield greater benefit at a cheaper price.

Priority 2 Actions

Priority 2 actions include all potential management actions that have the same rating for survival improvement as for cost. These actions could include high/high, medium/medium, or low/low pairings. While additional separation of these subcategories is possible, it will be necessary to further explore the feasibility of these actions in order to prioritize them with a high level of confidence. For these actions, the level of benefit corresponds roughly to the level of effort. It should be noted that there is a relatively large number of Priority 2 actions. This reflects the fact that a significant level of effort is necessary in the estuary to improve salmonid survival, and many actions will need to be implemented if survival rates are to improve.

Priority 3 Actions

Priority 3 actions include all potential management actions that have a higher cost rating than survival improvement rating. These actions would yield survival improvements, but, compared to other actions, they are expensive relative to the level of survival improvement they would provide.

TABLE 5-3
Prioritization of Management Actions

Action	Survival Improvement	Cost	Priority
Restore off-channel habitat by breaching (or lowering) dikes and levees where possible.	High	Medium	1
Reduce the abundance levels of Caspian terns nesting on islands created by disposal of dredged material.	Medium	Low	1
Protect remaining high-quality off-channel habitat from degradation through regulatory, fee simple, and less-than-fee acquisition.	Medium	Medium	2
Upgrade up-river irrigation structures using water conservation best management practices to reduce evaporation and conveyance losses to improve estuary instream flows.	Medium	Medium	2
Implement stormwater and runoff best management practices in cities and towns.	Medium	Medium	2
Monitor the estuary for contaminants and restore contaminated sites where appropriate.	Medium	Medium	2
Implement pesticide and fertilizer best management practices to reduce estuary and upstream sources of toxic materials entering the estuary.	Medium	Medium	2
Protect intact riparian areas and restore riparian areas that are degraded.	Medium	Medium	2
Remove jetties and navigational structures that have low navigational value but high impact on estuary circulation and/or juvenile predation effects.	Medium	Medium	2
Establish legal instream flows for the Columbia River and tributaries that would prevent further degradation of downstream ecosystems.	Medium	Medium	2
Remove tide gates where appropriate.	Medium	Medium	2
Reduce the export of sand and gravels via dredge operations by using dredged materials beneficially.	Medium	Medium	2
Reduce entrainment and habitat effects resulting from main- and side-channel dredge activities in the estuary.	Medium	Medium	2
Implement water conservation best management practices for public and private water purveyors.	Low	Low	2
Study and mitigate the effects of entrapment of sediment in reservoirs.	Low	Low	2
Reduce the square footage of over-water structures in the estuary.	Low	Low	2
Increase macrodetrital inputs and other historical food sources in the estuary to compensate for reservoir phytoplankton production, which is a permanent ecosystem alteration.	Low	Low	2
Manage the hydrosystem to reduce reservoir surface heating.	Low	Low	2
Manage smallmouth bass, walleye, and channel catfish to prevent increases in abundance.	Low	Low	2

Reduce the effects of vessel wake stranding in the estuary.	Low	Low	2
Reduce the impacts on salmonids by pinnipeds.	Low	Low	2
Reduce the abundance levels of shad entering the estuary.	Low	Low	2
Implement best management practices to prevent new introductions of invertebrates in the estuary.	Low	Low	2
Upgrade tide gates where (1) no other option exists, (2) structures can provide appropriate access for juveniles, and (3) ecosystem function would be improved over current conditions.	Low	Low	2
Increase the effectiveness of aquatic noxious weed laws through education, monitoring, and enforcement.	Low	Low	2
Locate sources of industrial and commercial pollutants and take steps to reduce inputs.	Medium	High	3
Protect and restore timberland riparian areas for shade and future wood sources.	Medium	High	3
Incorporate estuary flow considerations into management of the hydrosystem to increase spring freshet flows.	Low	Medium	3
Incorporate estuary flow considerations into management of the hydrosystem to adjust the timing and increase the magnitude and frequency of flows to better mimic historical conditions.	Low	Medium	3
Increase spring flows to enhance the transport of sand and gravels through the estuary, plume, and nearshore.	Low	Medium	3
Incorporate water availability analysis in land use planning activities to ensure efficient use of water.	Low	Medium	3

Summary

The estuary recovery module identifies and prioritizes management actions by considering the limiting factors that each action addresses, the significance of the threat addressed by the action, the potential for improvement in survival, and the costs of the action. There is considerable uncertainty regarding the relative importance of the management actions, and assumptions about the actions will need to be tested to improve confidence about the prioritization. Thus the most important features in Tables 5-1, 5-2, and 5-3 are the actions themselves and the assumptions they are based on. Some actions will never be fully implemented because they are essentially infeasible. On the other hand, the level of effort required to observe measurable results in survival improvement may require the realization of every potential benefit.

CHAPTER 6

Monitoring, Research, and Evaluation

Goal

The goal of monitoring and research is to provide the factual scientific basis for measuring, identifying, and refining the effectiveness and efficiency of salmon recovery efforts in the Columbia River estuary and plume.

Background

The monitoring and research plan in this chapter recognizes and builds on previous planning processes to provide a single comprehensive framework for estuary monitoring and adaptive management in relation to salmon recovery. The monitoring and adaptive management elements of this plan are a refinement of other draft plans prepared for a variety of applications. Estuary and related salmon recovery monitoring and evaluation needs have previously been considered in other regional programs, including the following:

- Lower Columbia River Estuary Partnership (1998 and 2004b)
- Recovery plans for salmon species of the Columbia Basin listed under the U.S. Endangered Species Act (National Oceanic and Atmospheric Administration 2005)
- Washington and Oregon salmon recovery programs (Washington Salmon Recovery Funding Board 2002, Oregon Watershed Enhancement Board 2005)
- Federal Columbia River Power System Biological Opinion implementation (National Oceanic and Atmospheric Administration 2003, Johnson et al. 2004, Upper Columbia River Technical Team 2004, Independent Science Advisory Board and Independent Science Review Panel 2004)
- Northwest Power and Conservation Council's Columbia River Fish and Wildlife program (Lower Columbia River Estuary Partnership 2004a)
- Pacific Northwest Aquatic Monitoring Partnership (2005a and 2005b)
- Collaborative Systemwide Monitoring and Evaluation Project (Columbia Basin Fish and Wildlife Authority 2005)

Additional refinements to monitoring, research, and evaluation plans for the estuary will likely result from other recovery plans being developed throughout the Columbia Basin. This plan may also be updated based on a NMFS guidance document currently in development.

Strategy

This plan includes a programmatic regional framework for monitoring and research to guide evaluations of ecosystem and ESU-wide concerns for fish recovery. An ecosystem perspective is particularly important for the estuary because of the complexity and dynamic nature of interactions of biological and physical processes. In the estuary, the whole is truly more than the sum of the parts.

This plan identifies specific objective measures for monitoring the status and trends of salmon and factors that affect salmon in the estuary, monitoring the implementation and compliance of estuary protection and restoration measures, action effectiveness monitoring, and critical uncertainties research. This plan also discusses information management and an inventory of existing gaps in monitoring and research projects or programs.

Status and Trends Monitoring

Status and trends monitoring includes the collection of standardized basic information used to monitor broad-scale trends over time in the status of fish populations, conditions in the habitat they use, and other ecosystem factors that affect fish. Status and trends monitoring typically includes the core elements of any monitoring program (for example, annual fish numbers and survival rates). This information is the basis for evaluating the cumulative effects of suites of management actions on fish, habitat, and the ecosystem.

Implementation and Compliance Monitoring

Implementation and compliance monitoring involves monitoring of management actions to determine whether actions were implemented as planned and meet established laws, rules, or benchmarks.

Action Effectiveness Monitoring

Action effectiveness monitoring involves project-scale monitoring of local conditions to determine whether implemented actions were effective in creating the desired proximate change. Action effectiveness monitoring typically is used to determine whether project- or program-specific performance goals are met. This type of monitoring also includes post-project monitoring to see whether the actions continue to function as they were designed or intended. Note that in some cases necessary information may be provided by status monitoring but that project effectiveness monitoring generally requires focused evaluations of more specific parameters directly associated with actions to address specific threat categories.

Uncertainties Research

Uncertainties research consists of scientific investigations of critical assumptions and unknowns that constrain effective recovery plan implementation. Uncertainties include currently unavailable pieces of information required for informed decision making as well as studies to establish or verify cause-and-effect relationships between fish, limiting factors, and projects or programs meant to protect or enhance fish production or affect limiting factors (sometimes called action effectiveness research or validation monitoring).

Information Management

Scientific review, reporting, and data management measures are included to ensure efficient implementation of a comprehensive and complementary program as well as accessibility and effective application of the associated data.

Project and Program Inventory

A project and program inventory identifies the monitoring and research efforts that are currently under way and where gaps exist.

This plan recognizes different spatial and temporal scales appropriate to a variety of programmatic and project-specific applications of monitoring and research. Efficiencies are optimized by incorporating and adapting existing monitoring and research activities into the plan. Information gaps are identified that need to be addressed with new monitoring and evaluation activities while recognizing that the available resources limit implementation to the highest priorities and that tradeoffs exist between monitoring, research, and evaluation (MR&E) activities and measures that more directly contribute to fish recovery. Complementary monitoring and research elements are organized for optimal efficiency. Research is focused on the effective implementation of recovery measures rather than detailed mechanistic studies of relationships between fish and limiting factors. Provisions are incorporated for regional coordination and data distribution to maximize accessibility and applicability.

Status and Trends Monitoring

Objectives

- ***Objective 1: Describe status and trends in salmon and steelhead occurrence and performance in the estuary relative to historical and current baseline conditions.*** Monitoring of status and trends in salmon and steelhead occurrence and performance in the estuary will provide a systematic basis for evaluating the effects of conservation and restoration efforts in the estuary and other areas. Estuary effects may significantly limit or enhance the benefits of actions in other parts of the system.

- ***Objective 2: Describe status and trends in estuary physical habitats and habitat-forming processes of significance to salmon and steelhead relative to historical and current baseline conditions.*** Monitoring of estuary habitat conditions will provide a physical baseline for evaluating changes that affect salmon and steelhead. Monitoring and understanding habitat-forming processes and trends in factors that affect those processes is key to being able to interpret spatial and temporal patterns in habitat conditions.

- ***Objective 3: Describe status and trends in estuary ecosystem factors that affect salmon and steelhead relative to historical and current baseline conditions.*** The estuary is a dynamic and complex ecosystem. Monitoring must consider the potentially confounding influences of an array of ecosystem elements in order to effectively interpret fish and fish habitat information. For the purposes of this plan, ecosystem elements include other species, productivity, and linkages within the biological community.

Indicators

Indicators are characteristics or conditions that can be evaluated using measurable attributes or metrics. Potential indicators to be used in this plan are shown in Table 6-1. These indicators and metrics were synthesized primarily from Johnson et al. (2003) and Lower Columbia River Estuary Partnership (2004b). The indicators fall into three main categories:

- Salmon status. Critical salmon life stages in the estuary include juvenile for migration and rearing, and adult spawning. Significant migration and rearing occurs in the mainstem river, freshwater-saltwater transition zone, and plume. Significant spawning occurs primarily in the upstream portions of the mainstem. Juvenile status monitoring includes individual characteristics (occurrence, size, age, or condition), migration patterns, and survival rates. Adult status monitoring includes distribution, abundance, age composition, and origin (hatchery or wild).

- **Habitat status.** Habitat status monitoring involves a wide range of physical indicators, including morphology/bathymetry, macrohabitat availability, habitat quality, water quality, hydrology, sediments, plume conditions, oceanographic conditions, contaminants, and modifications or barriers.
- **Ecosystem status.** Ecosystem status monitoring addresses aquatic community structure, biological productivity, invasive species, and salmon predators.

TABLE 6-1
Potential Elements of a Comprehensive Status and Trends Monitoring Program

Indicator	Metrics
Salmon status	
Juvenile characteristics	Occurrence, size, age, condition, health, and genetic stocks
Juvenile migration	Pathways and rates
Juvenile survival rates	Tidal-freshwater reach, estuary reach, and the plume
Mainstem spawning	Distribution, abundance, age composition, and hatchery or wild origin
Habitat status	
Morphology/bathymetry	Depth, width, and area, including the floodplain
Macrohabitat availability	Amount by type (including wetlands and riparian zone)
Habitat quality	Vegetation, substrate, microdetritus accumulation, and woody debris
Water quality	Temperature, salinity, dissolved oxygen, gas supersaturation, turbidity, pH, groundwater level, and nutrients
Hydrology	Flow, velocity, surface elevation, tidal patterns, inundation regime, seasonal hydrograph, and flood history
Sediments	Particle size, organic content, accretion rates, and pore water salinity
Plume conditions	Seasonal size, shape, and characteristics
Oceanographic conditions	Sea surface temperature and elevation, circulation pattern, upwelling, biological productivity indicators, El Niños /La Niñas, Pacific Decadal Oscillation
Contaminants	Sediments, bioaccumulation, biological indicators, tissue samples, point sources, and spill events
Modifications and barriers	Inventory of dikes, ditches, levees, jetties, docks, tide gates, culverts, dredging, dredge spoil disposal, and fill sites

Ecosystem status	
Aquatic community structure	Distribution and relative abundance of key species (herring and anchovies, for example)
Biological productivity	Phytoplankton, zooplankton, and benthos abundance and composition
Invasive species	Species list, distribution and relative abundance of key species
Salmon predators	Relative abundance of Caspian terns, cormorants, northern pikeminnow, and pinnipeds

Approach

Salmon Status

Salmon status and trend monitoring objectives will require at least three distinctly different sampling elements, each with a specific protocol.

Juvenile Index Sampling. Periodic sampling of juveniles at index sites with seine, trap net and/or trawl gear provides data on occurrence and characteristics in the estuary through the duration of the migration period. The intent of this sampling is to represent seasonal and annual patterns in fish numbers and run characteristics as fish move through the estuary. Juvenile index sampling sites might be stratified to include mainstem, mixing zone, and plume sample sites so that differences within the estuary can be characterized. Different habitat types will need to be represented to reflect differences between species and life stages. Juvenile sampling will include a mixture of fixed index sites, where fish can be effectively sampled under a wide range of conditions, and randomly selected sites, which are used to verify the applicability of the fixed sites. Sampling will occur in every year to provide the statistical power to distinguish long-term trends from high year-to-year variability. Sampling also will be stratified by time period within each year to control the effects of seasonal variation in numbers and characteristics of juveniles and adults. This work might be coupled with a comprehensive juvenile distribution and habitat use survey identified under critical uncertainties research. The study design will consider incorporation of data for historical and ongoing juvenile salmon studies. Juvenile index sampling will complement the smolt monitoring program that is currently being implemented at Snake and Columbia River dam sample sites.

Juvenile Migration and Survival Sampling. Information on migration patterns and survival might be obtained from intensive mark-recapture or telemetry studies, although both approaches have their limitations. Mark-recapture studies would require capture of large numbers of juveniles and may not be feasible in the estuary. Telemetry studies would be limited by tagging and technical constraints, although new acoustic tagging technology appears to provide an effective alternative for larger juveniles, including steelhead, stream-type chinook, and coho. Juvenile migration and survival studies using telemetry would employ random marking of fish throughout the run and detection at a series of fixed site receivers in the estuary and ocean.

Adult Spawning Surveys. Mainstem adult spawner monitoring will rely on systematic redd and carcass surveys of chinook and chum index sites in the Columbia River gorge. Surveys will include redd and fish counts at regular intervals throughout the spawning period and carcass samples for age composition and origin. Supplemental surveys are also appropriate for evaluating the significance and suitability of index sites. Adult surveys are ongoing.

Habitat status

Phased Approach. A core habitat inventory and status monitoring program will be implemented in phases. First, a hierarchical habitat classification system will be developed to provide an integrated concept for habitat evaluations. Next, remote sensing will be used to survey and characterize the entire estuary at a landscape scale. Third, a site-specific pilot habitat study will be conducted to provide a basis for evaluation of sampling method, sampling design, and statistical analysis options (Johnson et al. 2003). Results of the pilot study will provide the basis for planning a comprehensive inventory of current estuary habitat conditions (Lower Columbia River Estuary Partnership 2004b). A long-term monitoring program will then be designed based on results of the comprehensive inventory (Lower Columbia River Estuary Partnership 2004b). Supplemental sampling also will be needed to completely address some habitat indicators.

Habitat Classification System. Habitat status assessments will be greatly facilitated by the development of a classification system based on hydrologic, geomorphic, bathymetric, and land cover criteria (Lower Columbia River Estuary Partnership 2004b). Classifications of habitat types will be used to measure and describe changes over time. The system will also be used to stratify habitat sampling.

Remote Sensing Survey. The remote sensing survey will map conditions throughout the estuary at a broad scale based on aerial photos and Light Detection and Ranging (LIDAR, a remote sensing method involving analysis of light reflection and absorption of an illuminated target to measure target properties, including distance and composition). Results will provide a template and framework for more detailed assessments.

Pilot Physical Survey. A pilot study will field-test sampling protocols and identify potentially serious problems in the environmental study. It will identify the efficiency of sampling methods, size of sample units, number of samples required to obtain the desired precision of estimate, and large-scale spatial patterns that will require stratification (Green 1979). Results provide initial validation of the hierarchical habitat classification system for use in developing sampling strata and ground truth cover-type analyses from remotely sensed imagery.

Comprehensive Physical Inventory. The inventory will be a one-time intensive effort designed to characterize habitat conditions and differences throughout the 243-kilometer estuary based on fine-scale data. Site sampling will be conducted in a stratified random sampling scheme to characterize variability among and within strata. Strata will include estuary reaches, habitat types, and seasons. Fixed sample sites may also be incorporated into the sampling design to provide data for action-effectiveness monitoring of specific projects or to build on long-term data sets from other estuary monitoring programs. The inventory is designed to support specific refinements in the sampling design before the regular long-term monitoring program begins. Inventory results will be used to produce appropriate null hypotheses and identify a sampling frequency and distribution suitable to the variability associated with specific attributes of the system (Lower Columbia River Estuary Partnership 2004b). The inventory will characterize a broad suite of habitat parameters of which only a subset will likely be incorporated into the subsequent monitoring program.

***Physical Indicator Monitoring**.* The long-term monitoring program will sample a subset of representative habitat parameters and sites at periodic intervals in a stratified rotational sampling design. Metrics and sites will be determined based on inventory results. Sites will be sampled on a rotating basis. For instance, a 5-year rotational design might involve annual sampling of a subset of all monitoring sites to be repeated every 5 years.

***Focused Physical Monitoring**.* Core estuary habitat indicators will be addressed by the phased site-specific sampling, but other habitat parameters will be better addressed with surveys focused specifically on plume characteristics, oceanographic conditions, contaminants, and modifications or barriers.

Ecosystem Status

Conceptual Ecosystem Model. A comprehensive conceptual description of the estuary ecosystem will provide a unifying framework for further considerations of ecosystem status (Johnson et al. 2003).

Biological Indictors. A wide variety of potential biological indicators of aquatic community structure and productivity have been discussed in existing estuary plans (Johnson et al. 2003, Lower Columbia River Estuary Partnership 2004b). Example indicators include the distribution and relative abundance of key fish, phytoplankton, zooplankton, benthos, and macrophyte species. These data can be expensive to collect and difficult to interpret. Collecting all information at every sample site is likely not a realistic alternative. For the purposes of salmon recovery planning, appropriate indicators and metrics can be selected from the menu of choices based on the conceptual model and the significance and application of linkages to salmon.

Relation to Habitat Status Monitoring. Inventory and monitoring of biological indicators related to ecosystem function can be approached in a similar fashion to the habitat surveys. In many cases, biological and physical sampling can occur in the same experimental design and sampling sites. Concurrent sampling to the extent possible can provide for multivariate analysis of linkages and relationships.

Focused Monitoring. Several ecosystem elements lend themselves to a focused rather than generalized sampling program. For instance, predator monitoring can best be accomplished with index sampling specifically designed to address specific subjects. Fish predator, bird, and marine mammal assessments are currently based on sampling programs specifically designed for those purposes.

Implementation/Compliance Monitoring

Objectives

- ***Objective 1: Identify tasks involved in the implementation of each action.*** Tasks are project- or program-level activities by which an action is implemented.
- ***Objective 2: Identify parties responsible for each implementation task.*** Every task is associated with a responsible party. Parties may include federal agencies, state agencies, local government, or nongovernmental organizations.

- ***Objective 3: Identify a schedule for implementation of each task.*** Each task will ultimately be implemented according to a prescribed schedule identified based on the overarching goals of this plan.
- ***Objective 4: Inventory whether tasks associated with each action have been implemented.*** Implementation/compliance monitoring involves determining whether tasks have been implemented by responsible parties according to the prescribed schedule.

Approach

Implementation/compliance monitoring is intended to determine the degree to which actions identified in this plan have been implemented by responsible parties. This plan identifies a suite of potentially beneficial actions that address limiting factors and threats to salmon in the estuary. The plan does not obligate any party to implement any specific action or identify the degree of implementation effort required. The success or failure of the plan will ultimately depend on the combination of implementation effort and the effectiveness of actions that are implemented. Implementation and compliance monitoring will provide more immediate feedback on progress toward recovery than either action effectiveness or status and trend monitoring.

Implementation/compliance monitoring will be based on tasks related to each action, parties responsible for each task, and a task schedule, all of which remain to be determined. A template for this evaluation is outlined in Table 6-2. Ideally, tasks and a schedule will be identified for each action as part of a continuing plan implementation process. Implementation/compliance monitoring can also be based on a survey of related activities by effective parties even where no formal task and schedule implementation plan has been developed.

TABLE 6-2
Example Elements of an Implementation/Compliance Monitoring Evaluation

					Implemented?	
Threat	Action	Responsibility	Task	Schedule	Yes	No
Threat 1	Action A	Party i	Task a	(dates)	TBD	TBD
		Party i	Task b	(dates)	TBD	TBD
		Party ii	Task c	(dates)	TBD	TBD
	Action B	…	…	…	…	…
	Action C					
Threat 2	Action A					
	…					
…	…					

Action Effectiveness Monitoring

Objectives

- ***Objective 1: Evaluate the effectiveness of actions to address effects of flow regulation.*** Flow regulation by the hydro system affects habitat conditions, habitat-forming processes, and water quality in the estuary. This plan includes actions for flow guidelines and dissolved gas abatement.

- ***Objective 2: Evaluate the effectiveness of actions to address effects of off-channel habitat losses.*** Off-channel habitats appear to be critical for salmon rearing in the estuary. This plan includes actions to protect, restore, and reconnect off-channel habitats affected by diking and filling.
- ***Objective 3: Evaluate the effectiveness of actions to address effects of water withdrawal.*** Water withdrawals affect habitat availability and quality. This plan includes irrigation, water conservation, and water planning actions.
- ***Objective 4: Evaluate the effectiveness of actions to address effects of urban and industrial practices.*** Urban and industrial practices affect water quality and quantity. This plan includes actions to address stormwater runoff and contaminants.
- ***Objective 5: Evaluate the effectiveness of actions to address effects of upstream timber practices.*** Upstream timber practices affect temperature, water quality, runoff patterns, and sediment inputs. This plan includes actions to implement effective management practices.
- ***Objective 6: Evaluate the effectiveness of actions to address effects of jetties, navigational, and over-water structures.*** Jetties and navigational and over-water structures directly affect salmon habitat conditions in the estuary. This plan includes actions to ameliorate these effects.
- ***Objective 7: Evaluate the effectiveness of actions to address effects of altered predator/prey relationships.*** Human activities have affected the numbers and predation rates on salmon by fish, birds, and marine mammals. The plan includes actions to manage these effects.
- ***Objective 8: Evaluate the effectiveness of actions to address effects of dredging.*** Channel maintenance activities can substantially affect habitat conditions at dredge removal and disposal sites. This plan includes actions related to channel maintenance activities.
- ***Objective 9: Evaluate the effectiveness of actions to address effects of ship wakes and ballast water.*** Ship wakes can strand juvenile salmon on beaches, and ballast water has been widely documented as a source of invasive species introduction. This plan includes actions related to shipping practices.

Indicators

Example indicators for action effectiveness monitoring are identified in Table 6-3.

Approach

Each action will be the subject of specific monitoring to evaluate its effectiveness. Action effectiveness monitoring generally requires specific metrics, experimental designs, or sampling protocols in addition to or at a different scale than those already included in systematic status and trend monitoring. The intent of action effectiveness monitoring is to evaluate the proximate local effects of specific actions, projects, or classes of projects and provide more immediate feedback to guide the scale and nature of action implementation. In many cases, action effectiveness monitoring is focused on the specific mechanisms by which an action or project influences a particular limiting factor or threat.

Action effectiveness monitoring is not merely an analysis of status and trend monitoring data, although data can be related and monitoring sites can sometimes be selected to address multiple purposes. Where status and trend monitoring is intended to evaluate the large-scale cumulative response of key system components to multiple actions, action effectiveness monitoring will address a representative subset of projects and programs addressing each category of recovery action. Where status and trend monitoring might include an estuarywide inventory of off-channel habitats, action effectiveness monitoring might track the numbers of tide gates that potentially impede passage and improvements in fish passage following modification or removal. Where status and trend monitoring might evaluate long-term sediment transport and deposition rates in the estuary, action effectiveness monitoring might include a focused test and control study of tributary sediment inputs relative to different watershed conditions. Where status and tend monitoring might provide data on the relative abundance of salmon predators like northern pikeminnow, action effectiveness monitoring of the pikeminnow management program might collect specific additional data on size composition, angler harvest, and exploitation rates for a thorough evaluation of this action. Where habitat status and trend monitoring can provide a long-term picture of the net effect of channel dredging activities in concert with other estuary habitat-forming processes, action effectiveness monitoring might involve things like fish movement studies during in-water work periods or recolonization rates of benthic organisms at removal and disposal sites.

More specific indicators and metrics will be developed in specific evaluation plans for each category of action. Specific plans will include measurable variables or parameters to address each objective, study design (spatial and temporal scale, tests and controls, statistical criteria, etc.), data collection methods and reference examples, and analyses and decisions in response to results.

TABLE 6-3
Examples of Action Effectiveness Monitoring of Estuary Actions

Threat	Action	Indicator
Flow regulation	Downstream flow guidelines	Freshet and flood frequency relative to historical baseline
	Dissolved gas abatement	Frequency and downstream extent of standard exceedances Correlations of operations and gas supersaturation
Dikes and filling	Off-channel habitat protection	Inventory of protected areas and type of protection
	Off-channel habitat restoration	Number, area, and relative contribution of projects Post-restoration habitat monitoring of representative sites
	Passage improvements at tide gates	Before and after upstream relative abundance at representative sites
Water withdrawal	Upgrade irrigation structures	Diversion volumes (actual)
	Water conservation measures	Per-capita water use
	Dedicated instream flows	Reserved volumes

	Water availability planning	Long-term trends in instream flow in reference sites
Urban and industrial practices	Stormwater runoff	Water quality levels relative to state and federal water quality standards
	Riparian protection and restoration	Inventory of projects
	Contaminants	Inventory of sources and problem sites
Upstream timber practices	Best management practices	Roads, culverts, riparian conditions, area by stage, and rotation intervals in representative watersheds.
Jetties and navigational and over-water structures	Removal of obsolete problem structures	Inventory of structures and functions
Altered predator/prey relationships	Caspian tern redistribution	Distribution and index of salmon predation rates
	Pikeminnow management	Annual harvest, harvest rate, and population age structure
Dredging	Channel maintenance	Affected area
	Disposal guidelines	Volume and disposition
Ship wakes and ballast	Best management practices	Targeted monitoring

Uncertainties Research

Objectives

- ***Objective 1: Determine the significance and effects of the estuary on salmon viability.*** The estuary is clearly a significant habitat in the salmon life cycle, but the nature and magnitude of effects are complex and unclear. Understanding these effects will be critical to the efficient design of a comprehensive and effective salmon recovery effort.

- ***Objective 2: Determine how conditions for salmon in the estuary have been affected by human activities.*** Understanding human effects on estuary conditions of significance to salmon will provide a focus for protection and conservation actions.

- ***Objective 3: Determine what can we do to improve conditions for salmon in the estuary.*** A variety of potentially beneficial actions have been identified, but additional information is needed to accurately assess benefits relative to costs and tradeoffs among other alternatives.

Uncertainties

Critical uncertainties related to each research objective are detailed in Table 6-4. These uncertainties were synthesized primarily from Johnson et al. (2003) and Lower Columbia River Estuary Partnership (2004a).

Salmon Significance. Related uncertainties involve juvenile salmon habitat requirements, survival factors, food web dynamics, saltwater transition, and adult predation by pinnipeds.

Effective assessments will require improvements in juvenile telemetry and genetic stock identification techniques.

Human Effects. Related uncertainties involve delayed mortality of juvenile salmon, the effects of flow regulation on habitats and habitat-forming processes, juvenile density and habitat interactions, and introduced species effects.

Remedies. Related uncertainties include habitat restoration priorities and opportunities, the benefits of flow management on juvenile rearing and adult spawning habitats, and the cumulative effects of multiple recovery actions.

Approach

Reduction of critical uncertainties will require a series of carefully designed research studies and experiments. Effective approaches will likely involve a combination of mechanistic studies of limiting relationships, empirical studies of action and response, and synthesis of multivariate data, including other monitoring information. Status and action effectiveness monitoring data will likely address some but not all of the research information needs. Specific research plans will be required for each item. Research plans will include test hypotheses to be evaluated, considerations of alternative approaches, limitations and uncertainties, and applications and responses to potential alternative research findings.

TABLE 6-4
Potential Elements of an Uncertainties Research Program

Objective	Uncertainty
Salmon	• Juvenile salmon habitat use, preferences, and limitations (spatial and temporal distribution of juveniles by species and type) • Factors affecting estuary survival of juvenile salmon • Effects of estuarine food web dynamics on salmon (food, feeding, prey selectivity, prey availability, bioenergetics, growth) • Factors affecting saltwater transition of juvenile salmonids (physiology, condition, health) • Significance and projections of pinniped predation on salmon • Significance and projections of cormorant predation on salmon • Improvements and applications of acoustic tracking techniques for evaluating the distribution and movements of juvenile salmon • Improvements and applications of genetic stock identification techniques (single nucleotide polymorphisms, for example)
Human effects	• Significance of condition and migration history on estuary and ocean expression of potential delayed mortality of juvenile salmon • Effects of historical changes in annual hydrograph and flood frequency on estuary conditions, habitats, and habitat-forming processes (hydrodynamics, morphology, sediment transport, and deposition processes) • Effects of incremental changes to hydrograph to mimic spring freshets • Significance of density-dependent rearing effects on salmon and interactions with habitat changes.

	• Significance of salmon interactions with key introduced species, including shad
Remedies	• Habitat restoration priorities and opportunities for juvenile salmon • Effects of alternative flow management regimes on estuary conditions, habitats, and habitat-forming processes • Evaluation of flood control constraints on hydrosystem regulation • Optimum dam operations for mainstem spawning habitat availability, quality and spawning success given operational constraints • Predictive tools for estimating the cumulative effects of multiple recovery actions on salmon (conceptual, qualitative, or quantitative models based on improvements in our understanding of the linkages between physical and biological processes on survival and production in response to selected restoration measures)

Data and Information Management

Data and other information pertinent to this plan are appropriately collected by many parties for a wide variety of applications, including but not limited to this plan. Data analysis and management are performed at a project and sometimes agency level, but not at a program level (Johnson et al. 2004). It is not desirable or feasible to centrally coordinate all data collection activities. However, application of pertinent data to the evaluation of this plan will be facilitated by the organization of a coordinated collaborative information network that includes the following elements[1]:

- Incorporation of data produced by existing programs and information systems to avoid duplication of effort.
- Establishment of an estuary MR&E information-sharing committee that includes technical representatives of action agencies, the Lower Columbia River Estuary Partnership, and other entities involved with plan implementation and monitoring. This information-sharing committee would complement corresponding groups of policy representatives responsible for plan implementation.
- Integration with other basinwide MR&E groups, including the Pacific Northwest Aquatic Monitoring Partnership (PNAMP) and the Collaborative Systemwide Monitoring and Evaluation Project (CSMEP).
- Regular written project-level reporting by MR&E partners.
- Coordinated system for peer review of project plans and reports.
- Periodic estuary MR&E workshops to present new data, discuss findings, and exchange information on future plans.
- Establishment of a central, Web-accessible repository and library for estuary data and references.
- Guidelines for metadata standards to facilitate data exchange and application.

[1] Adapted from Johnson et al. (2003) and Lower Columbia River Estuary Partnership (2004b).

- Centrally facilitated program-level review for comprehensive synthesis and evaluation of pertinent information relative to the goals and objectives of this plan.
- Periodic program-level summary reports.
- Consistent participation and funding commitments by partners.

Project and Program Inventory

A gap analysis of existing projects and programs will be a critical next step in implementation of the monitoring, research, and evaluation elements of this plan. A wide variety of monitoring, research, and evaluation activities are currently under way or planned in the estuary. The gap analysis will compare existing and planned projects and programs with the needs and objectives for monitoring, research, and evaluation identified in this plan. The product of this exercise will be a list of items not effectively addressed by existing projects and programs. The exercise is similar to the gap analysis that will evaluate how well existing projects and programs address the recovery actions identified by this plan.

CHAPTER 7

Perspectives on Implementation

Putting the Estuary in Context

The Columbia River estuary and plume play a unique role in the life cycles of chinook, chum, and coho salmon and steelhead trout. Each year millions of juvenile salmon and steelhead enter the estuary from rivers as distant as the Similkameen flowing out of Canada, the Clearwater in Idaho, the Cowlitz in Washington, and the John Day in Oregon. To complete its life cycle, each individual salmon or steelhead must migrate downstream to the estuary for growth and protection from predators as it undergoes the remarkable physiological changes needed for it to live in seawater. Years later, these salmon and steelhead return to the estuary after adult life in the ocean and again undergo dramatic physiological changes, this time to prepare them for the freshwater environment in which they will make their upstream journey home.

The estuary provides essential habitat for Columbia River anadromous salmon and steelhead during one of the three distinct stages in their complex life cycles. Salmon and steelhead spawn and rear in freshwater, they enter and exit saltwater in the estuary, and they mature and grow in the ocean. If any one of these three environments—freshwater, estuarine, or saltwater—fails to provide what salmon and steelhead need at that particular stage in their life, the result is salmonid mortality, regardless of how well the other two environments are meeting the needs of salmon and steelhead. In other words, all three of these environments must be functioning adequately if salmon and steelhead are to achieve a level of productivity that yields at least two new fish for every pair that spawns.

Over the last 200 years, the ability of the Columbia River estuary to meet the needs of salmon and steelhead has been seriously compromised. There is no question about the extent of changes in the estuary: the timing, magnitude, and duration of flows do not resemble those of historical flows, access to the estuary floodplain has been virtually eliminated, sediment transport processes that depend on flows and upstream sediment sources are radically different than they were historically, water quality has degraded as a result of contamination and temperature increases, and there have been fundamental changes at the base of the estuarine food web, with associated alterations in inter- and intra-species relationships. In view of these changes, what survival improvements can be expected as a result of management actions in the estuary and plume?

The answer to this question is elusive for a number of reasons. In its technical memorandum *Salmon at River's End,* NOAA's Northwest Fisheries Science Center uses a conceptual framework to make a simple yet important point. The authors hypothesize that analysis of salmon and steelhead in the estuary must take into account changes occurring in all life cycle stages of ESUs because changes in other life cycles may affect the genetic and spatial diversity of ESUs using the estuary.

As described in Chapter 2, life history strategies expressed by Columbia River ESUs are less diverse today than they were 200 years ago because of upstream habitat losses, estuary habitat losses, and changes in the fish themselves as a result of hatchery and harvest effects. This means that, currently, the relationships between the fish and their habitats are much less robust than in historical times. It is difficult to envision a properly functioning estuary without a basinwide understanding of the genetic and spatial diversity needs of all ESUs in each stage of their life cycles. Conversely, the same is true of freshwater and ocean environments—if a life history strategy is not supported because estuary habitat has been eliminated or the habitat is there when the fish aren't present, a mismatch occurs that likely reduces survival.

The estuary is unique among the diverse environments that salmon and steelhead use to complete their life cycles. Unlike tributaries, which have to provide habitat only for the few salmon and steelhead populations that use that particular river or stream, the estuary has to provide habitat for all Columbia River salmon and steelhead populations. The estuary must have sufficient quantities of habitat available—of the right types, at the right times, and in the right configurations—to accommodate the estimated 150 distinct populations of salmon and steelhead that use the estuary during critical life stages. If estuary habitats are lost or are not available at the right times for each population's unique life history strategy, competition for those habitats may result in mortality. And although it may seem daunting to manage the Columbia River and its tributaries to meet the distinct needs of such a large number of populations, it is this very diversity in life history strategies that has allowed Columbia River ESUs to make use of all of possible habitats, survive catastrophic events over millennia, and persist until today.

Limitations of Scientific Knowledge

Until recently, the Columbia River estuary and plume have not received much attention in terms of their respective roles in the life cycle of salmon and steelhead. But research on other river systems may provide insight into the ecology of the estuary and plume. For example, recent research in the Skagit River indicates that density dependence mortality (competition for habitats) occurs there because of the loss of habitats that fall chinook use during estuarine residency. The fact that the loss of key habitats is of the same order of magnitude in the Columbia River estuary as in the Skagit delta suggests that density dependence mortality may also be occurring in the Columbia. However, the Columbia River estuary is a much bigger and more complex system, with larger flows and many times more ESUs that depend on it. Whether density dependence mortality is actually occurring there cannot yet be determined. To solve this puzzle, a better understanding of the availability of estuarine habitats and their use by various populations is necessary. It will require focused effort to unravel the estuary's secrets.

The state of the science on the estuary, as documented through peer-reviewed literature, is stronger in some areas than others. There is a good body of literature that identifies limiting factors and threats in the estuary itself. However, the plume and nearshore have been understudied and only recently speculated to be important to yearling juveniles. In general, the literature does a good job of documenting changes from the historical template (a 44 percent reduction in the number of spring freshets, for example), but most often it does not estimate corresponding salmonid losses. In addition, very few literature sources prescribe treatments. Some exceptions include actions identified in the *Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan* and its supplement (Lower Columbia River Estuary

Partnership 2004a) and the *FCRPS Biological Opinion Remand* (Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers 2004).

Over the next few years, it seems likely that the maturation of modeling efforts (some of which are currently under way) will better equip scientists to estimate the potential for improvement for salmon and steelhead in the estuary. However, even with new models, additional research and studies will need to be directed toward programs to determine, from a management action perspective, what it is possible to accomplish in the estuary given existing physical, financial, political, and social constraints.

For example, several of the management actions in Table 5-3 are intended to improve the timing, magnitude, and duration of flows entering the estuary. But what really is the potential for incrementally adjusting the hydrograph to enhance salmon and steelhead survival in the estuary? Given other fish management objectives, the need for flood control, the economics of power generation, and other constraints, the actual feasibility of altering the hydrograph to benefit salmon and steelhead is difficult to determine. Recent changes in the operation of the hydrosystem demonstrate that some change is possible; however, it is unknown whether incremental improvements in estuarine flows will improve survival by themselves or whether overbank flows are needed to achieve measurable improvements. Also unknown is whether the risks and economic burden associated with changing the hydrosystem still more would be acceptable to the public.

The other important factor in estimating improvement in survival relates to the implementation of actions. Individual management actions can be implemented to varying degrees, and the effectiveness of an action depends in part on how fully it is implemented. Table 5-2, which evaluates potential management actions, deals with this issue by stating a key assumption about the implementation of each management action. Assumptions about both implementation and feasibility are key components of this estuary recovery plan module and warrant further discussion by scientists, politicians, stakeholders, and citizens. This is particularly true because the contemporary literature has not fully explored these critical elements and tends to articulate what is not possible rather than what is possible.

This estuary recovery module is designed to highlight what may be possible. In nearly every case, an effort has been made to identify a management action that theoretically could improve survival in the estuary and plume. A fundamental premise in the module is that all actions have inherent constraints and therefore cannot be implemented fully. For example, the breaching of dikes is a high priority, but there are only limited opportunities to breach dikes because of impacts on land use. If it is true that few or no potential management actions can be implemented completely, then perhaps the best strategy is to implement all of the actions to the degree that is practicable in terms of costs and potential survival improvements. This would include upstream actions identified in other modules and recovery plans because, as described in other parts of this document, the ecology of the estuary is in many ways the sum total of upstream and ocean effects.

One additional factor should be considered in the discussion about the feasibility of actions, constraints, and level of effort. Human population numbers are projected to increase steadily through the twenty-first century. To reverse declining salmon productivity trends, efforts must do more than just slow the current rate of ecosystem degradation. The level of effort must be such that there are absolute improvements in the physical and biological conditions that act as limiting factors to salmon and steelhead in the freshwater, estuarine, and ocean environments.

Habitat changes in the estuary and plume have contributed to the decline of salmon and steelhead in the Columbia River basin. The sheer magnitude of these changes indicates that impacts to salmon and steelhead in the estuary and plume are significant. The need to improve conditions in the estuary and plume is urgent and should receive a high level of attention across the basin. These improvements will be expensive because many of the threats have altered the basic ecosystem of the estuary and will require substantial changes in the way we manage resources. Finally, it will be important to put forth enough effort that monitoring efforts can detect beneficial changes in the estuary and plume.

CHAPTER 8

References

Ackerman, N. 2002. *Effects of Vessel Wake Stranding of Juvenile Salmonids in the Lower Columbia River, 2002: A Pilot Study*. Sandy, OR.

Bauersfeld, K. 1977. *Effects of Peaking (Stranding) of Columbia River Dams on Juvenile Anadromous Fishes below the Dalles Dam, 1974 and 1975.* Washington Department of Fisheries. Vancouver, WA.

Beamer, E., A. McBride, C. Greene, R. Henderson, G. Hood, K. Wolf, K. Larsen, C. Rice, and K. Fresh. 2005. *Delta and Nearshore Restoration for the Recovery of Wild Skagit River Chinook Salmon: Linking Estuary Restoration to Wild Chinook Salmon Populations*. Skagit River System Cooperative, LaConner, Washington.

Bisbal, G.A., and W.E. McConnaha. 1998. "Consideration of Ocean Conditions in the Management of Salmon." *Canadian Journal of Fisheries and Aquatic Sciences* 55:2178-2186.

Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers. 2004. *Final Updated Proposed Action for the FCRPS Biological Opinion Remand*. Portland, OR.

Bottom, D.L., C.A. Simenstad, J. Burke, A.M Baptista, D.A. Jay, K.K. Jones, E. Casillas, and M.H. Schiewe. 2005. *Salmon at River's End: The Role of the Estuary in Decline and Recovery of Columbia River Salmon*. U.S. Dept. Commerce, NOAA technical memorandum. NMFS-NWFSC-68, 246p.

Brodeur, R.D., J.P. Fisher, R.L. Emmett, C.A. Morgan, and E. Casillas. 2005. *Species Composition and Community Structure of Pelagic Nekton off Oregon and Washington under Variable Oceanographic Conditions*. Marine Ecology Progress Series.

Casillas, E. 1999. Role of the Columbia River Estuary and Plume in Salmon Productivity. Symposium on Ocean Conditions and the Management of Columbia River Salmon. Edited by Gustavo Bisbal. Portland, OR.

Columbia Basin Fish and Wildlife Authority. 1990. *Review of the History, Development, and Management of Anadromous Fish Production Facilities in the Columbia River Basin.* Unpublished manuscript, 52 p., U.S. Fish & Wildlife Service.

Columbia Basin Fish and Wildlife Authority. 2005. *Collaborative, Systemwide Monitoring and Evaluation Project.*

Columbia Basin Trust. *A Guide to Major Hydropower Projects of the Columbia River Basin*. Castlegar, British Columbia.

Columbia River Channel Improvement Reconsultation Project. Web site. Accessed on November 28, 2005. http://www.sei.org/columbia/background.html.

Cornwell, T.J., D.L. Bottom, and K.K. Jones. 2001. *Rearing of Juvenile Salmon in Recovery Wetlands of the Salmon River Estuary.* Oregon Department of Fish and Wildlife, Information Reports 2001-05, Portland.

Ebel, W.J. 1969. *Supersaturation of Nitrogen in the Columbia River and Its Effect on Salmon and Steelhead Trout.* U.S. National Marine Fisheries Service, Fishery Bulletin 68: 1-11.

Fresh, K.L., E. Casillas, L.L. Johnson, and D.L. Bottom. 2005. *Role of the Estuary in the Recovery of Columbia River Basin Salmon and Steelhead: An Evaluation of the Effects of Selected Factors on Salmonid Population Viability*. NOAA technical memorandum, Northwest Fisheries Science Center, National Marine Fisheries Service. Seattle, WA. 136 pp.

Fuhrer, G.J., Q. Tanner, J. Morace, S. McKenzie, and K. Skach. 1996. *Water Quality of the Lower Columbia River Basin: Analysis of Current and Historical Water-Quality Data through 1994.* U.S. Geological Survey, Portland, OR 1996.

Gaar, E. 2005. *Draft Guidelines for Limiting Factors and Threats Assessments.* Draft memorandum. NOAA Fisheries Service.

Genovese, P.V., and R. L. Emmett. 1997. *Desktop Geographic Information System for Salmonid Resources in the Columbia River Basin.* U.S. Dept. of Commerce, NOAA technical memorandum. NMFS-NWFSC-34.

Green, R.H. 1979. *Sampling Design and Statistical Methods for Environmental Biologists.* Wiley, New York.

Hinton, S., and R. Emmett. 1994. *Juvenile Salmonid Stranding in the Lower Columbia River, 1992 and 1993.* National Marine Fisheries Service. Seattle, WA 1994.

Independent Scientific Advisory Board and Independent Scientific Review Panel. 2004. *A Joint ISAB and ISRP Review of the "Draft Research, Monitoring, & Evaluation Plan for NOAA-Fisheries 2000 Federal Columbia River Power System Biological Opinion*. Portland, OR.

Independent Scientific Advisory Board. 2000. *The Columbia River Estuary and the Columbia River Basin Fish and Wildlife Program*. Northwest Power and Conservation Council. Portland, OR.

Jay, D.A., and P. Naik. 2002. "Separating Human and Climate Impacts on Columbia River Hydrology and Sediment Transport." Pp. 38-48 in G. Gelfenbaum and G. Kaminsky, eds., *Southwest Washington Coastal Erosion Workshop Report 2000,* U.S. Geological Survey Open File Report, 02-229. 308 pp.

Jay, D.A., and T. Kukulka. 2002. "Impacts of Columbia River Discharge on Salmonid Habitat." Manuscript submitted to the *Journal of Geophysical Research*.

Jay, D.A., and T. Kukulka. 2003. "Impacts of Columbia River Discharge on Salmonid Habitat." Manuscript submitted to the *Journal of Geophysical Research*. Revised 2003.

Johnson, G.E., H. Diefenderfer, T. Berquam, B. Ebberts, C. Tortorici, and J. Wilcox. 2004. *Plan for Research, Monitoring, and Evaluation of Salmon in the Columbia River Estuary.* Prepared by the Pacific Northwest National Laboratory to Bonneville Power Administration.

Johnson, G.E., R.M. Thom, A.H. Whiting, G.B. Sutherland, N. Ricci, J.A. Southard, B.D. Ebberts, and J.D. Wilcox. 2003. *An Ecosystem-Based Approach to Habitat Restoration Projects with Emphasis on Salmonids in the Columbia River Estuary.* Prepared by the Pacific Northwest

Lichatowich, J. 1999. *Salmon Without Rivers*. Island Press, Washington D.C.

Loge, F.J, M.R. Arkoosh, T.R. Ginn, L.L. Johnson, and T.K. Collier. 2005. *Impact of Environmental Stressors on the Dynamics of Disease Transmission*. Environment, Science and Technology.

Lott, M.A., 2004. *Habitat-Specific Feeding Ecology of Ocean-Type Juvenile Chinook Salmon in the Lower Columbia River Estuary.* Master's thesis. University of Washington.

Lower Columbia Fish Recovery Board. 2004. *Lower Columbia Salmon Recovery and Fish and Wildlife Subbasin Plan, Vol I.* Lower Columbia Fish Recovery Board, Washington.

Lower Columbia River Estuary Partnership. 1998. *Lower Columbia River Estuary Plan, Volume 2. Aquatic Ecosystem Monitoring Strategy.*

Lower Columbia River Estuary Partnership. 2002. *Draft Lower Columbia River and Columbia River Estuary Subbasin Summary.* Prepared for the Northwest Power Planning Council.

Lower Columbia River Estuary Partnership. 2004a. *Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan.* Prepared for the Northwest Power and Conservation Council. May 28, 2004.

Lower Columbia River Estuary Partnership. 2004b. *Columbia River Estuary Habitat Monitoring Plan.*

Lower Columbia River Estuary Partnership. 2005 *Geographical Information System Map*. Data accessed on November 28, 2005. Portland, OR.

Morgan, C.A., A.D. Robertis, and R.W. Zabel. 2005. *Columbia River Plume Fronts. I. Hydrography, Zooplankton Distribution, and Community Composition*. Marine Ecology Progress Series.

Nash, J.D., and J.N. Moum. 2005. "River Plumes as a Source of Large-Amplitude Internal Waves in the Coastal Ocean." *Nature*. Volume 437, September 15, 2005.

National Marine Fisheries Service. 2000. *Biological Opinion, Reinitiation of Consultation on the Operation of the Federal Columbia River Power System, including the Juvenile Fish Transportation Program, and 19 Bureau of Reclamation Projects in the Columbia Basin.*

National Oceanic and Atmospheric Administration. 2003. *Draft Research, Monitoring, and Evaluation Plan for NOAA Fisheries 2000 Federal Columbia River Power System Biological Opinion.* Jordan, C.J. Geiselman, M. Newsom, and J. Athern, editors. Seattle.

National Oceanic and Atmospheric Administration. 2005. *Draft Columbia River Salmon Recovery Plans.*

National Research Council. 2004. *Managing the Columbia River: Instream Flows, Water Withdrawals, and Salmon Survival*. The National Academies Press. Washington D.C.

Neal, V.T. 1972. “Physical Aspects of the Columbia River and Its Estuary.” Pp. 19-40 In A.T. Pruter and D.L. Alverson (eds.). *The Columbia River Estuary and Adjacent Ocean Waters*. Bioenvironmental Studies. Univ. Wash. Press, Seattle, WA.

Northwest Power and Conservation Council. 2000. *Return to the River*. Pp 367-412. Portland, OR.

Northwest Power and Conservation Council. 2001. *Dams and Hydropower*. Personal communication (e-mail). Portland, OR.

Oregon State University. 1998. *A Changing Columbia Basin, 1770 – Present*. Accessed on September 20, 2005. http://oregonstate.edu/instruct/anth481/sal/crintro1.htm.

Oregon Watershed Enhancement Board. 2005. *The Oregon Plan for Salmon and Watersheds, 2003-05 Biennial Report.* Salem.

Pacific Northwest Aquatic Monitoring Partnerships. 2005a. *Strategy for Coordinating Monitoring of Aquatic Environments in the Pacific Northwest.* (http://www.reo.gov/PNAMP).

Pacific Northwest Aquatic Monitoring Partnerships. 2005b. *Estuary Workgroup Strategy.* July 29, 2005, version.

Podobnik, B. 2005. *Pollution in Portland: Toxic Emissions in the Metropolitan Area*. Lewis and Clark College, Portland, OR.

Robertis, R.D., C.A. Morgan, R.A. Schabetsberger, R.W. Zabel, R.D. Brodeur, R.L. Emmett, C.M. Knight, G.K. Krutzikowsky, E. Casillas. 2005. *Columbia River Plume Fronts. II. Distribution, Abundance, and Feeding Ecology of Juvenile Salmon*. Marine Ecology Progress Series.

Roby, D.D., K. Collis, D. Lyons, D. Craig, J. Adkins, A. Myers, and R. Suryan. 2002. “Effects of Colony Relocation on Diet and Productivity of Caspian Terns.” *Journal of Wildlife Management* 66:662-673.

Santen, D. 2004. *Survey Finds 81 Introduced Aquatic Species in the Lower Columbia River; Eight Previously Undetected.* Portland State University.

Simenstad, C.A., D. Jay, C.D. McIntire, W.Nehlsen, C.R. Sherwood, and L.F. Small. 1984. *The Dynamics of the Columbia River Estuarine Ecosystem, Vol. I and II.* Columbia River Estuary Data Development Program, Astoria, OR.

Sinclair, M., and P. Solemdal. 1998. “The Development of ‘Population Thinking’ in Fisheries Biology between 1878 and 1930.” *Aquat. Living Resour. 1:189-213.*

Sytsma, M., J. Cordell, J. Chapman, and R. Draheim. 2004. *Lower Columbia River Aquatic Nonindigenous Species Survey 2001-2004.* U.S. Coast Guard and Fish and Wildlife Service.

Thom, R. 2001. Development of a Conceptual Model for the Columbia River Navigational Channel Improvement Project Reconsultation Process. Battelle Marine Sciences Laboratory, Sequim, WA.

Thom, R., and D. Williams. 2001. "Marine and Estuarine Shoreline Modification Issues." White paper submitted to the Washington Departments of Fish & Wildlife, Ecology, and Transportation. Olympia, WA.

Thomas, D.W. 1983. *Changes in the Columbia River Estuary Habitat Types over the Past Century*. Columbia River Estuary Data Development Program, Columbia River Estuary Task Force, Astoria, Oregon.

U.S. Environmental Protection Agency. 2005. *Global Warming – Climate.* 2005. Web site accessed on November 9, 2005. http://yosemite.epa.gov/oar/globalwarming.nsf/content/index.html

Upper Columbia Regional Technical Team. 2004. *Monitoring Strategy for the Upper Columbia Basin.* Report by BioAnalysts to Upper Columbia Salmon Recovery Board.

Varanasi, U. 2005. *Biological Implications of Recent Ocean Conditions*. Memorandum to Regional Administrator.

Washington Salmon Recovery Funding Board. 2002. *Comprehensive Monitoring Strategy and Action Plan for Watershed Health and Salmon Recovery.* Washington.

Williams, G., and R. Thom. 2001. *Marine and Estuarine Shoreline Modification Issues.* Washington Department of Ecology and Transportation.

Wissmar, R.C., and C.A. Simenstad. 1998. *Variability of Riverine and Estuarine Ecosystem Productivity for Supporting Pacific Salmon*. University of Washington. Seattle, WA.